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LIMNOLOGICAL INVESTIGATION OF THE MUSKEGON COUNTY, MICHIGAN, WASTEWATER STORAGE LAGOONS. PHASE 1

W. Randolph Frykberg, et al

Western Michigan University

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Environmental Research Laboratory

September 1975

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During the period of study, the East Lagoon received most of the wastewater, while the West Lagoon received mostly land drainage and seepage water. Due to these different waters in each lagoon, differences in most of the parameters were apparent between the two lagoons. Chironomid larvae comprised virtually all of a scant benthic population in both lagoons, with different dominant genera in each body of water. The dominant zooplankton in the East Lagoon were cyclopoid copepods, with Cyclops vernalis the most common form, while calanoid copepods and Daphnia were dominant in the West Lagoon. The number of zooplankton per liter consistently remained higher in the East Lagoon than in the West Lagoon. The green algae were the most common phytoplankton in both lagoons, with different dominant genera in each.

Chlorophyll a and primary productivity were measured and numerous physical-chemical parameters were also investigated.

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Phase One

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The limnology of two 850 acre wastewater storage lagoons was investigated from September 1973, shortly after the initial filling, through August 1974. Special emphasis was placed upon the biological aspects of these lagoons.

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Chlorophyll a and primary productivity were measured and numerous physical-chemical parameters were also investigated.

This report was submitted in partial fulfillment of Order number 04J1P01534 by Western Michigan University, Biology Department, under the partial sponsorship of the Environmental Protection Agency. Work was completed as of August 1974.

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SECTION I

CONCLUSIONS AND RECOMMENDATIONS

Two 850 acre lagoons, which are part of the Muskegon Wastewater Land Irrigation System, were investigated from September 1973, shortly after their initial filling, through August 1974. Special emphasis **was** placed on the biological aspects of the water quality and the benthic and planktonic populations. The water quality of the two lagoons differed: that of the East Lagoon was primarily semi-treated municipal and industrial wastewater; that of the West Lagoon was usually only seepage and ground water.

Turbidity, BOD, total organic carbon, nutrients, anions, and metals (except for magnesium) were all higher in the East Lagoon than in the West. The East Lagoon was also slightly less alkaline.

The benthic fauna was limited, with chironomids accounting for virtually all (97.5%) of the scant population. Glyptotendipes spp. was the most common midge in both lagoons; Procladius culiciformus was in higher numbers in the seepage water West Lagoon while Chironomus plumosus was more common in wastewater East Lagoon. Limnodrilus, the only oligochaete genus to be found in the lagoons, was present only in very limited numbers. Their presence would indicate that the lagoons will support benthic organisms and that a more dense and diverse benthic community will develop in the future. However, a longer colonization time will be required to allow the benthic macroinvertebrates to reach their potential density.

Although considerable variability through time was found in the mean number of zooplanktonic organisms per liter in each lagoon and in the major groups, the number of zooplankton per liter was consistently higher in the nutrient and organically enriched East Lagoon than in the seepage water West Lagoon. Cyclopoid copepods, especially Cyclops vernalis, were more common in the East Lagoon, while Daphnia and Diaptomus were the common forms in the West.

The number and types of phytoplankton and protozoans varied greatly both in time and location. Green algae clearly dominated this population in both lagoons, comprising 55.4% of the phytoplankton and protozoan

populations in the East Lagoon and 67.4% in the West Lagoon. The proportion of green algae steadily increased with the distance from the source of the wastewater discharge in the East Lagoon. Blue-green algae represented 25.3% of the phytoplankton and protozoan population in the West Lagoon. A large Cyanophyta bloom (composed of Aphanizomenon flos-aquae) on 29 August 1974 accounted for nearly all of the blue-greens (93.6%) in the West Lagoon during this study.

Although the findings for one year are presented in this report, data collection and analyses have continued at the same frequency. Recent results, not included in this report, show some interesting topics that may be investigated throughout this and possibly next year.

These special studies recommended could include areas such as:

A.) Heterotrophic assimilation and its relation to autotrophic production.

B.) Rate of incorporation of heterotrophic and autotrophic carbon by the indigenous zooplankton population. Also, investigate the population dynamics of these two planktonic communities.

C.) Follow the seasonal dynamics of phytoplankton, chlorophyll a, and primary productivity over the next year, especially that of the West Lagoon which is presently receiving wastewater. This phase in particular will be of interest from the viewpoint to document either the same pattern of succession as those observed this past year in the East Lagoon or a development of a different population.

D.) Increase the number of benthic samples to three and follow the colonization rate in both lagoons. Associated with this study would be analyses of sediment for potential toxic substances that may possibly explain the relatively slow rate of colonization of these storage lagoons.

SECTION II

INTRODUCTION

GENERAL

The Muskegon County, Michigan, Wastewater Management System is an alternative to conventional wastewater treatment and disposal methods. It offers a technique to help clean up the waters of the world by the handling of pollutants as resources out of place.

The effluent from traditional wastewater treatment plants contains many nutrients and other components, some of which may be toxic, increasing the eutrophication rate and pollutional load of waterways. Rather than discharge this nutrient-rich and pollution causing treated wastewater to a stream, river, or lake, the Muskegon System uses it as irrigation water and allows the soil and plants to "polish" the effluent and perform the final treatment (traditionally called "Tertiary Treatment"). This enables the effluent to act as a fertilizer and a soil conditioner.

HISTORY

The idea of land treatment of wastewater is not new. In fact, the use of animal and human waste as soil conditioners and fertilizers dates back to antiquity. Stansbury (1974) reports that sewage farming extends back beyond the Roman Empire. In 1559 a project was designed to treat wastes from Bunslav, Prussia, by applying domestic sewage to the land for disposal. This land treatment system continued for over 300 years (Godfrey, 1973; Thomas, 1973). During the latter part of the 19th Century, some of the most effective sewage treatment systems were well-managed, agriculturally productive farms (Stevens, 1974). Berlin, Germany, disposed of its waste during this period on four farms, totaling 19,000 acres, on

the sandy plains of northern Germany. During periods of hard frost or heavy storms, sewage was stored in ponds for later use. In the 1870's Paris, France, began using land disposal for its wastewater. Initially, the sewage was given to farmers for irrigation, but soon the wastewater was so much in demand that the city sold it to the farmers. Today some several thousand acres on a sandy outwash plain near Herblay are still used for treating a portion of the wastewater from Paris. During the late 1800's London, England, also treated and disposed of part of its wastewater on several sewage irrigation farms.

A wastewater land treatment system was established for Melbourne, Australia, in 1893. As the volume of wastewater increased, the farm was expanded. In 1963, the system comprised 26,809 acres and treated the waste from approximately 2.5 million people, or about 100 million gallons of domestic and industrial wastewater per day. This system also includes lagoons to hold peak loads of wastewater and to provide further stabilization of the wastewater.

Land treatment of wastewater began in the United States in the 1870's, but usually on a more limited scale than in other countries. The State Insane Asylum in Augusta, Maine, began the first reported attempt at land treatment in the United States in 1872 (Stevens, 1974). Later that same year a farm near Pullman, Illinois, 14 miles south of Chicago, was the first municipal farm to use wastewater irrigation. The failure of this farm several years later was blamed on poor management, as too much wastewater was applied at too rapid a rate, overtaxing the soil. San Antonio, Texas, constructed lagoons and began applying sewage to the land around 1900 (Gloyna, 1971).

A survey of 15 western states showed 113 localities practicing land treatment of wastewater in 1935 (Hutchins, 1939). Of significance is the fact that most of these systems were still in operation in 1972 (Thomas, 1973). Presently about 1,000 United States municipalities are treating and disposing of their wastewater through land treatment techniques (Godfrey, 1973; Stansbury, 1974). Most of these systems are quite small, comprising less than 1,000 acres. The largest facility of this type in the United States is the Muskegon System which utilizes 10,800 acres

and is designed to treat 45 million gallons of wastewater per day (Demirjian, 1973).

LAGOONS

A common component of land treatment of wastewater systems is a lagoon or a series of lagoons. These lagoons can serve as reservoirs during periods when irrigation should be diminished or halted, such as during very wet periods or when the ground is frozen, when toxic spills occur, and/or to serve as a biological system giving further treatment to the wastewater prior to disposal on the land. Lagoons, without being a component of land treatment systems, have also been used for centuries to store and treat animal and human waste. In 1962 about 1,650 sewage lagoons were treating municipal wastewater in the United States (Forges and Mackenthun, 1963) and some 1,600 lagoons were treating industrial wastes (Forges, 1963). These studies, however, did not specify the number of lagoons operating alone or the number of lagoons operating in conjunction with land treatment systems.

OBJECTIVES OF STUDY

Although there has been a fair amount of experience with land treatment systems and/or wastewater lagoons, there is a noticeable dearth of information in the literature concerning the limnology of wastewater lagoons, especially lagoons which are as large and as deep as the Muskegon lagoons. There is even less information available on the biological aspects of these lagoons. Yet, these lagoons are important to the successful overall operation of a wastewater management system, with or without land treatment. As a result, to manage these lagoons, to make necessary predictions and assumptions, and in order to understand what is occurring in the facility, it is necessary to develop an understanding of the numbers, types, distribution and fluctuation of organisms; that is the population dynamics, within the lagoons.

This investigation was concerned with the limnology of the wastewater storage lagoons in the Muskegon System, with particular emphasis upon the biological aspects of these waters. A goal of this study was to generate

basic information concerning these lagoons. Hopefully, this background information can be incorporated into more intensive studies on the metabolism, energy relations, and trends within large wastewater storage lagoons. These studies are needed in order to gain a better understanding of the interrelationships within lagoons of this type and in order to permit a more scientific management of wastewater systems.

THE MUSKEGON SYSTEM

The Muskegon County Wastewater Management System treats municipal effluents from the greater Muskegon area and industrial effluents from various industries, including two chemical companies, a paper mill, and a foundry. During this study, the flow of incoming wastewater was approximately 28 million gallons per day, 65% of which was industrial waste.

A network of interceptor sewers, force mains and six pumping stations collect and deliver the combined municipal-industrial wastewater to a large central pumping station. From this station, four pumps with a maximum pumping capacity of 56,000 gallons per minute drive the combined wastewater 11 miles to the 10,800 acre sandy treatment site. At the site, the raw wastes are first discharged into three biological treatment cells (Fig. 1). Each cell is equipped with 12 mechanical surface aerators and six mixing units, with 1,000 combined horsepower per cell, providing a complete mix system and an average detention time of three days. The effluent from these cells, which is comparable in quality to that achieved by conventional secondary treatment, flows by gravity to either or both of two 350 acre storage lagoons. This storage capacity of 5.1 billion gallons offers operating flexibility to the system. During periods of heavy rainfall, or when the ground is frozen, it is not necessary to irrigate. Also, in the event of a toxic material spill which could be detrimental to the biological treatment cells, the untreated wastewater can flow directly into the storage lagoons to be assimilated and biodegraded. These lagoons also provide additional waste stabilization during periods of normal operation.

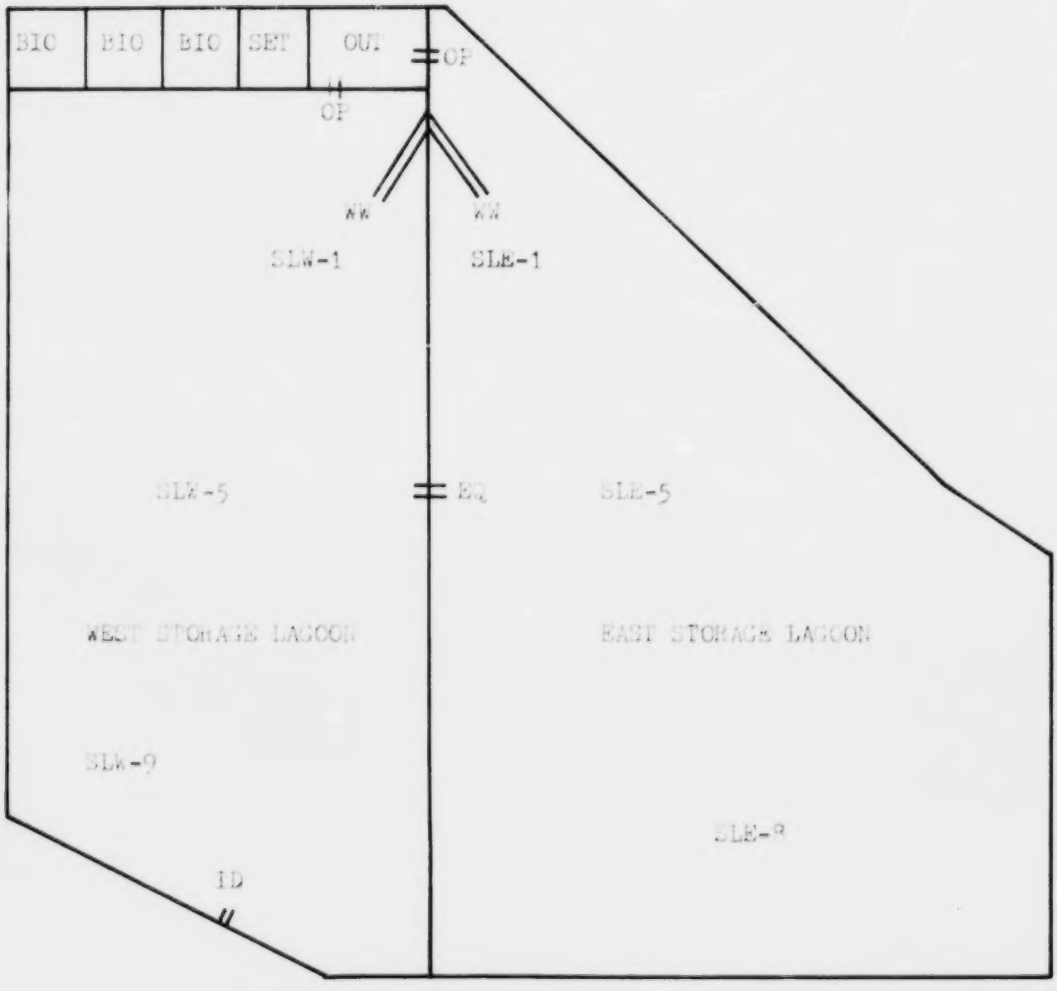
In order to prevent seepage from entering the ground water outside of the waste management site, a drainage or interception ditch encircles both

FIGURE 1

MUSKEGON WASTEWATER STORAGE LAGOONS

Key to abbreviations

BIO = Biological Treatment Cells
OUT = Outlet Pond
SET = Settling Pond
ID = Point of discharge of interception ditch water
OP = Point of discharge from lagoon to outlet pond
WW = Point of discharge of wastewater
EQ = Equalizing gate



lagoons, and seven drainage wells are located at the west end of the lagoon area. Water collected in the ditch or withdrawn from the wells is returned to the West Lagoon.

From the storage lagoons the water flows to an outlet pond and then to a chlorination chamber prior to being used as irrigation water. During periods of high demand the storage lagoons can be bypassed, with the treated wastewater flowing into a settling pond and then to the outlet pond. Further operational flexibility is provided by gates which control the amount of wastewater flowing into either lagoon, from one lagoon to the other, and from the lagoons to the outlet pond. The locations of these gates are indicated in Figure 1.

Further information on this system can be found in the literature (Anonymous, 1973; Bastian, 1973; Bauer Engineering, 1973; Chaiken, et. al., 1973; Demirjian, 1973; Forestell, 1973; Sheaffer, 1972; Snow, 1973; Teledyne Triple R, 1973).

In late May, 1973, a small amount of effluent was being discharged into both lagoons. At this time there was some rainwater in the basins, but the bottoms were not yet covered. Due to evaporation and seepage, the bottom on the lagoons were not covered until August, 1973, at which time the flow had increased to about 28 MGD. By this time, the constituents of the wastewater had helped to seal the bottom.

SECTION III

PROJECT DESIGN AND METHODOLOGY

DESIGN

This study began in August 1973 and continued through August 1974. Three stations were established in each lagoon, as shown in Figure 1. The station locations and designations correspond to those used by the managers of the system.

Each lagoon was sampled biweekly. During periods of open water, all samples were taken within 50 feet of the station using an aluminum boat. For safety reasons, when the lagoons were ice-covered samples were taken 50 feet from and perpendicular to the shore and in line with the station. Stations SLE-5 and SLW-5, the stations farthest from shore in both the East and West Lagoons, were not sampled during periods of ice cover.

A 2.2 liter, horizontal, opaque, non-metallic Van Dorn bottle was used to collect samples for analysis of the following parameters: phytoplankton and protozoans; chlorophyll *a* and phaeophytin; primary productivity; temperature; Dissolved Oxygen (DO); five-day biochemical oxygen demand (BOD); turbidity; conductivity; pH; total organic carbon; metals, including calcium, iron, magnesium, manganese, potassium, sodium, and zinc; nutrients, including orthophosphate, nitrate, and ammonia nitrogen; chlorides; and sulfate. An Ekman dredge was used to collect replicate benthos samples and a number 12 plankton net (mesh openings equal to 0.15 millimeter) was used to collect replicate zooplankton samples.

METHODS

When feasible, standard procedures and techniques, as described in Standard Methods for the Examination of Water and Wastewater (American Public Health

Association, 1971)and in Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents (Weber, 1973), were adhered to as close as possible. Specifics of each parameter are further described below.

BENTHOS. After screening the samples through a No. 30 sieve (28 meshes per inch, 0.595 millimeter openings) and preserving any specimans in 70% ethanol, qualitative and quantitative analyses of the organisms found were carried out with the aid of stereoscopic and compound microscopes. Numerous taxonomic references aided the identification of the benthic macroinvertebrates (Beck, 1968; Curry, 1962; Edmondson, 1959; Grodhaus, 1967; Johannsen, 1934-37; Mason, 1973; Pennak, 1953; Robeck, 1957; Ross, 1959; Usinger, 1956).

In order to make genus and species identification of the midges, it was necessary to prepare head and body mounts of these organisms. Rather than using the conventional but very time consuming technique of clearing the midges in KOH, rinsing, and then mounting (American Public Health Association, 1971; Mason, 1973; Weber, 1973), the midges were mounted directly into polyvinyl lactophenol (Meier, 1974). This substance acts as both a clearing agent and a mounting media.

Data from replicate samples were averaged, and the results reported as number of individuals per tenth square meter. The mean diversity, $\bar{d}$, and equitability, e, was calculated for each station using the following formulas (Weber, 1973):

$$\bar{d} = \frac{3.21928}{N} \left(N \log_{10} N - n_i \log_{10} n_i \right)$$

$$e = \frac{s'}{s}$$

where

N = the total number of individuals at the designated station over the complete period of study

n_i = the total number of individuals in the i^{th} species

s' = a tabulated value

s = the number of taxa in the sample

ZOOPLANKTON. Although a number 20 net is recommended for the capture of nauplii and other small zooplankters, a number 12 net was utilized to prevent the clogging by the unusually large quantities of suspended matter. Several taxonomic references were valuable aids to identification (Bousfield, 1958; Brooks, 1957; Gannon, undated; Edmondson, 1959; Pennak, 1953). Data from replicate samples were averaged and the results were reported as the number of organisms per liter.

PHYTOPLANKTON AND PROTOZOA. Samples were initially collected at one foot and/or three feet. From 26 April 1974 throughout the rest of this investigation, sample depths were related to the transparency within each lagoon. In the West Lagoon, collection was at a depth equal to the secchi disk transparency and also at one-half of this depth. Due to the very shallow transparency in the East Lagoon, samples could not meaningfully be collected at these depths, and therefore, collection was at the secchi disk transparency and at one and one-half feet. The samples were preserved with Lugol's solution and allowed to settle for several weeks. Due to the low number of plankters present, the samples were concentrated by withdrawal of the supernatant with a suction tube.

A Palmer-Maloney cell, rather than a Sedgwick-Rafter cell, was used for quantitative and qualitative analysis because of the higher magnification required for nannoplankton. Twenty fields were examined in each of several slide preparations and the results averaged for each sample. The clump count was used, with all filamentous or colonial organisms counted as one unit. References relied upon for the analysis of the phytoplankton and protozoa included Berges (1971), Edmondson (1959), Kudo (1971), Parrish (1968), Patrick and Reimer (1966), Prescott (1962), and Weber (1966 and 1973).

PRIMARY PRODUCTIVITY. Primary productivity was measured with the carbon-14 method of Steeman-Neilson (1952), incorporating only minor modifications (Jordan, 1970; Saunders et al., 1962; Weber, 1973). Table 1 indicates the formula which was used in order to obtain the amount of carbon fixed per hour.

TABLE 1

Conversion of CIM to Carbon Fixed

Conversion equation	$P = \frac{r}{n} \times C \times f$ (Saunders, et al., 1962)
P	Photosynthesis in mg C/m^3
r	cpm counted (uptake of radioactive carbon)
C	19.2×10^3 mg C/m^3 (available inorganic carbon in the lagoons)
f	1.06 (Isotope conversion factor)
n	4.27×10^5 (total available radioactive carbon in cpm: microcuries used X counter efficiency X millipore absorption factor X disintegration per minute per microcurie)
Microcuries used	$\frac{32,000}{40,290}$ (scintillation cpm/cpm per microcurie)
Counter efficiency	0.25
Millipore absorption factor	0.838
Disintegrations per minute per microcurie	2.22×10^6
Final equation for lagoons	$P = r \times 0.0477$

CHLOROPHYLL a. After filtering 100 ml of each sample on a 0.45 micron membrane filter, the filters were frozen until in vitro analysis in acetone extracts by flourometry was accomplished.

CONDUCTIVITY. A platinum electrode type specific conductance cell with a cell constant of 1.0 ± one per cent was used. Results were reported in micro-mhos.

DISSOLVED OXYGEN. These samples were fixed in the field immediately after collection, and titrated in the laboratory.

pH. A hydrogen ion selective glass electrode in combination with a saturated calomel reference electrode was used to determine pH by the electrometric method. Results were reported in standard pH units.

SECCHI DISK TRANSPARENCY. A standard 20 cm diameter black and white secchi disk was used. Results were reported in centimeters.

TURBIDITY. A Hach Model 2100A Turbidometer was used for direct measurement of turbidity by the Nephelometric method. Results were reported in Formazin Turbidity Units (equivalent to Jackson Turbidity Units).

NITRATE NITROGEN. The concentration of nitrate nitrogen was determined through a copper-cadmium reduction of nitrate to nitrite. The nitrite thus produced was quantified using sulfanilamide (diazotizer) and N-1-naphthyl-ethylenediamine (couplet). The resulting highly colored dye was measured colorimetrically and the results were reported as mg per liter NO_3^-.

AMMONIA NITROGEN. The concentration of ammonia nitrogen was determined by distillation followed by nesslerization. Results were reported as mg per liter NH_4^+.

ORTHOPHOSPHATE. The concentration of orthophosphate was determined by colorimetry, without preliminary filtration, digestion, or hydrolysis, using ammonium molybdate in the vanadomolybdophosphoric acid method. Results were reported as mg per liter $PO_4^=$.

SULFATE. The concentration of sulfate was determined using the Barium-Methythymol Blue colorimetric procedure. Results were reported as mg per liter $SO_4^=$.

CHLORIDES. The concentration of chloride was determined by liberation of the thiocyanate ion from mercuric thiocyanate, followed by a reaction with the ferric ion. Results were reported as mg per liter Cl^-.

TOTAL ORGANIC CARBON. The concentration of total organic carbon (TOC) was determined using a Beckman Model 915 Total Carbon Analyzer. Results were reported as mg per liter carbon.

METALS. The concentrations of calcium (Ca), iron (Fe), magnesium (Mg), manganese (Mn), sodium (Na), potassium (K), and zinc (Zn) were determined using flame ionization photometry and atomic absorption spectroscopy. Results were reported as mg per liter of the specific metal.

SECTION IV

RESULTS AND DISCUSSION

The data gathered during this investigation are presented in a separate appendix. Summary data only are presented in this report. The results of each parameter will be discussed individually and the trends or relations between parameters will be discussed where appropriate.

WASTEWATER FLOW PATTERNS DUE TO GATE OPERATING POSITIONS

During this investigation, the operating positions of the gates which controlled inflow, outflow, and mixing between lagoons were altered (Table 2). There was no noticeable effect upon any of the parameters due to the equalizing gates being open from 17 August through 26 September 1973 and from 29 March through 5 July 1974.

Ammonia nitrogen and secchi disk transparency were the only parameters noticeably affected when the gate to the outlet pond was opened in the East Lagoon. These effects are noted in the appropriate portions of this section.

BENTHOS

The benthic macroinvertebrate population was, surprisingly, very limited. This community comprised a small number of organisms representing only a few taxonomic groups.

The percentage composition, by group and by station, is presented in Table 3. This table also indicates the number of samples taken at each station and the number of samples at each station that contained no benthic macroinvertebrates. Each station-group category contains two numbers as a percentage. The first number was obtained by dividing the number of indicated organisms at the specified station by the total number of all

TABLE 2

Gate Operating Positions and Wastewater Flow Patterns

8-13-73 through 8-17-73	Flow directly from biological treatment cells to outlet pond. Gates between the biological treatment cells and the East and West Lagoon (hereafter referred to as east gate or west gate) closed. Outlet gate closed.
8-18-73 through 9- 4-73	Flow into both East and West Lagoons with equalizing gate also open. Outlet gates closed.
9- 5-73 through 9- 7-73	Flow directly into outlet pond. East and west gates closed, equalizing gate open. Outlet gates closed.
9- 8-73 through 9-26-73	Flow into both lagoons, with equalizing gate also open. Outlet gates closed.
9-27-73 through 3-29-74	Flow into East Lagoon only. West gate, equalizing gate, and outlet gates all closed.
3-30-74 through 4-24-74	Flow into East Lagoon, equalizing gate open, outlet gates closed.
4-30-74 through 7- 5-74	Flow into East Lagoon. Equalizing gate and west outlet gate open. East outlet gate closed.
7- 6-74 through 8-31-74	Flow into East Lagoon. East outlet gate open, equalizing gate and west outlet gate closed.

TABLE 3

Percentage Composition and Occurrence of Benthos. The first number represents the percentage composition and the second number, in parentheses, represents the percentage occurrence. See text for further details.

TAXA	STATIONS							
	SLE-1	SLE-5	SLE-8	SLW-1	SLW-5	SLW-9	EAST, TOTAL	WEST, TOTAL
No. of samples	14	5	8	12	5	7	27	24
No. of samples with zero organisms found	6	2	2	2	0	2	10	4
I Arthropoda, Insecta	72.7 (57.1)	100.0 (60.0)	100.0 (75.0)	98.5 (83.3)	99.5 (100.0)	97.1 (71.4)	98.1 (63.0)	99.3 (83.3)
A. Diptera, Chironomidae	63.6 (50.0)	100.0 (60.0)	100.0 (75.0)	94.7 (83.3)	99.5 (100.0)	97.1 (71.7)	97.4 (59.3)	97.5 (83.3)
1. Pupae	9.1 (7.1)	0.8 (20.0)	3.2 (12.5)	0.0 (0.0)	5.0 (20.0)	0.0 (0.0)	2.6 (11.1)	2.5 (4.2)
2. Larvae	54.4 (50.0)	99.2 (60.0)	96.8 (75.0)	94.7 (83.3)	94.5 (100.0)	97.1 (71.4)	94.9 (55.5)	94.9 (83.3)
a. Chironomus plumosus	9.1 (7.1)	19.4 (40.0)	21.8 (37.5)	0.8 (8.3)	4.0 (40.0)	0.0 (0.0)	20.0 (22.2)	2.2 (12.5)
b. Cricotopus sp.	0.0 (0.0)	0.8 (20.8)	1.3 (12.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.0 (7.4)	0.0 (0.0)
c. Dicrotendipes modestus	9.1 (7.1)	0.0 (0.0)	1.3 (12.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.3 (7.4)	0.0 (0.0)

TABLE 3 CONTINUED

TAXA	STATIONS							
	SLE-1	SLE-5	SLE-8	SLW-1	SLW-5	SLW-9	EAST, TOTAL	WEST, TOTAL
d. *Parachironomus* sp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	2.3 (8.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.7 (4.2)
e. *Glyptotendipes* spp.	31.8 (28.6)	78.2 (40.0)	47.2 (75.0)	34.6 (33.3)	75.3 (80.0)	6.0 (28.6)	59.4 (44.4)	50.2 (41.7)
1) *G.* sp. A	0.0 (0.0)	9.8 (40.0)	11.0 (50.0)	18.8 (16.7)	28.7 (80.0)	0.0 (0.0)	9.7 (16.2)	20.6 (25.0)
2) *G.* sp. B	22.7 (21.4)	54.9 (40.0)	27.8 (75.0)	15.8 (25.0)	43.6 (80.0)	6.0 (28.6)	39.0 (40.7)	28.1 (37.5)
3) *G.* sp. C	9.1 (14.3)	13.5 (40.0)	8.4 (12.5)	0.0 (0.0)	3.0 (40.0)	0.0 (0.0)	10.6 (18.5)	1.5 (8.3)
f. *Procladius culiciformus*	4.5 (7.1)	0.8 (20.0)	22.6 (62.5)	57.0 (66.7)	15.2 (100.0)	85.1 (57.1)	11.9 (25.9)	40.8 (70.8)
g. *Tanytarsus* sp.	0.0 (0.0)	0.0 (0.0)	2.6 (12.5)	0.0 (0.0)	0.0 (0.0)	6.0 (14.3)	1.3 (3.7)	1.0 (4.2)
B. Odonata, Coenagrionidae	9.1 (7.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.6 (3.7)	0.0 (0.0)
C. Trichoptera	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	3.0 (14.3)	0.0 (0.0)	0.5 (4.2)
D. Ephemeroptera, Baetidae	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	2.3 (16.7)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.7 (8.3)

TABLE 3 CONCLUDED

FAUNA	STATIONS							
	SLE-1	SLE-5	SLE-9	SLW-1	SLW-5	SLW-9	EAST, TOTAL	WEST, TOTAL
E. Coleoptera, Elmidae	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.5 (16.7)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.5 (4.2)
II Mollusca, Gastropoda								
Physidae, Physa	9.1 (7.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.5 (20.0)	0.0 (0.0)	0.6 (3.7)	0.2 (4.2)
III Annelida, Oligochaeta								
Tubificidae, Limnodrilus	18.2 (7.1)	0.0 (0.0)	0.0 (0.0)	1.5 (8.3)	0.0 (0.0)	0.0 (0.0)	1.3 (7.4)	0.5 (4.2)

benthic macroinvertebrates at that station and multiplying the quotient by 100. This value is termed the percentage composition. The second number was obtained by dividing the number of occasions the indicated organism was found at the specified station by the number of benthic samples taken at that station and multiplying the quotient by 100. The resultant value is called the percentage occurrence.

Immature dipterans, of the family Chironomidae (non-biting midges), almost exclusively dominated the benthic community. This family, which was represented by seven genera, accounted for 97.5% (95.0% larvae + 2.5% pupae) of all the benthic organisms. On a by-station basis, the Chironomidae comprised 100% of the benthos at two stations, over 94% at three other stations, but only 63.6% at the station closest to the wastewater discharge, SLE-1. These high percentages are to be expected, as non-biting midges have dominated the benthic macroinvertebrate population in other wastewater storage-stabilization lagoons (Grodhaus, 1967; Kimerle and Enns, 1968). The above authors, though, also report that the Chironomidae breed so prolifically in lagoons that they often emerge in extremely large and troublesome numbers. This high population was not experienced at any time during the first year of operation of the Muskegon lagoons, where in 48 out of 52 samples the benthic macroinvertebrate fauna remained well below 100 organisms per tenth square meter. The greatest number of organisms was 150 per tenth square meter, all of which were Chironomidae. Thus the number of benthic organisms remained quite low throughout this study, in sharp contrast to the more common values of from 1,000 to 16,000 Chironomidae per tenth square meter in other wastewater lagoons (Kimerle and Enns, 1968).

The dominant genera varied from station to station. Procladius culiciformus was dominant at SLW-1 and SLW-9, comprising 57.0% and 85.1%, respectively, of the benthic population, while Glyptotendipes spp. dominated at SLE-5 and SLW-5, comprising 78.1% and 75.3%, respectively. The margin is not so clear at SLE-8, where Glyptotendipes spp. accounted for 47.2 %, Procladius culiciformus 22.6%, and Chironomus plumosus 21.8% of the benthic macroinvertebrate population. The dearth of organisms at SLE-1 makes the

percentages less meaningful than at the other stations.

The type of midges found in the Muskegon Lagoons appear to be representative of the normal lagoon insect fauna. In a study of 18 Missouri lagoons (Kimerle and Enns, 1968), Glyptotendipes barbipes, Chironomus plumosus, and Tanypus punctipennis (in the same family as Procladius, Tanypodinae) comprised more than 94% of the total number of insects collected in all lagoons. Based on Bureau of Vector Control records of larvae collected from 22 localitites, nine species of chironomids are considered to be common inhabitants of lagoons in California, including Procladius sp., Cricotopus sp., Glyptotendipes barbipes, two species of Tanypus, and four species of Chironomus (Grodhaus, 1967).

Oligochaetes were found on only two occasions, 21 December 1973 at SLS-1 (8 per tenth square meter), and 16 November 1973 at SLW-1 (4 per tenth square meter). They represented only one genus, Limnodrilus, a group which is usually common in organically polluted waters. It may take longer for the oligochaetes to proliferate in this new environment.

Empty snail shells were found in seven samples. The genus Physa was the most common, but three other genera were also present, as shown in Table 4.

TABLE 4

Empty Gastropoda Shells (No. per tenth square meter)

DATE	GENERA AND LOCATION
3-13-74	4 Physa (SLW-9)
5-28-74	6 Physa (SLW-1); 26 Physa (SLW-5)
6-28-74	2 Physa and 18 Gyraulus (SLW-5)
7-12-74	4 Physa (SLS-5)
8-29-74	2 Physa, 2 Campoloma, 6 Lymnaea and 6 Gyraulus (SLW-5); 2 Physa (SLW-1)

Since it was not known if these snails were living in the lagoons or if just the empty shells were washed in, they are not included in any further analyses. On only two occasions were both the snail body and shell of Physa found, 12 December 1973 at SLE-1 (4 per tenth square meter) and 29 August 1974 at SLW-5 (2 per tenth square meter).

The changes in the abundance of benthic organisms throughout this investigation are shown in Figures 2 and 3. Both lagoons experienced a decline in benthos from June to September, during the period when emergence occurred.

The number of benthic macroinvertebrate organisms at SLE-1 remained very low throughout the year, and in six of the 14 samples, no organisms were found. The mean number of benthic organisms found at this site was only 3.1 per tenth square meter. Due to this paucity of animals, no species diversity or equitability could be determined for this station. Since each of the stations contained so few benthic organisms, diversity and equitability were calculated on a per station basis rather than on the more common per sample basis. These results are presented in Table 5.

TABLE 5

Diversity Indices and Equitability for the Benthic Macroinvertebrate Community

	SLE-5	SLE-8	SLW-1	SLW-5	SLW-9
Diversity, $\bar{d}$	1.7623	2.4593	1.8623	1.8539	0.8351
Equitability, e	0.7298	0.9377	0.5259	0.7839	0.5122

This index of diversity, $\bar{d}$, is based on information theory and takes into account the number of species (i.e., richness of species) as well as the numerical distribution of individuals among the species (i.e., the relative importance of each species). Theoretically, it can range from zero to the log of the total number of individuals (Weber, 1973).

FIGURE 2
1973 - 1974
Changes in the Abundance of benthic organisms in the West Storage Lagoon

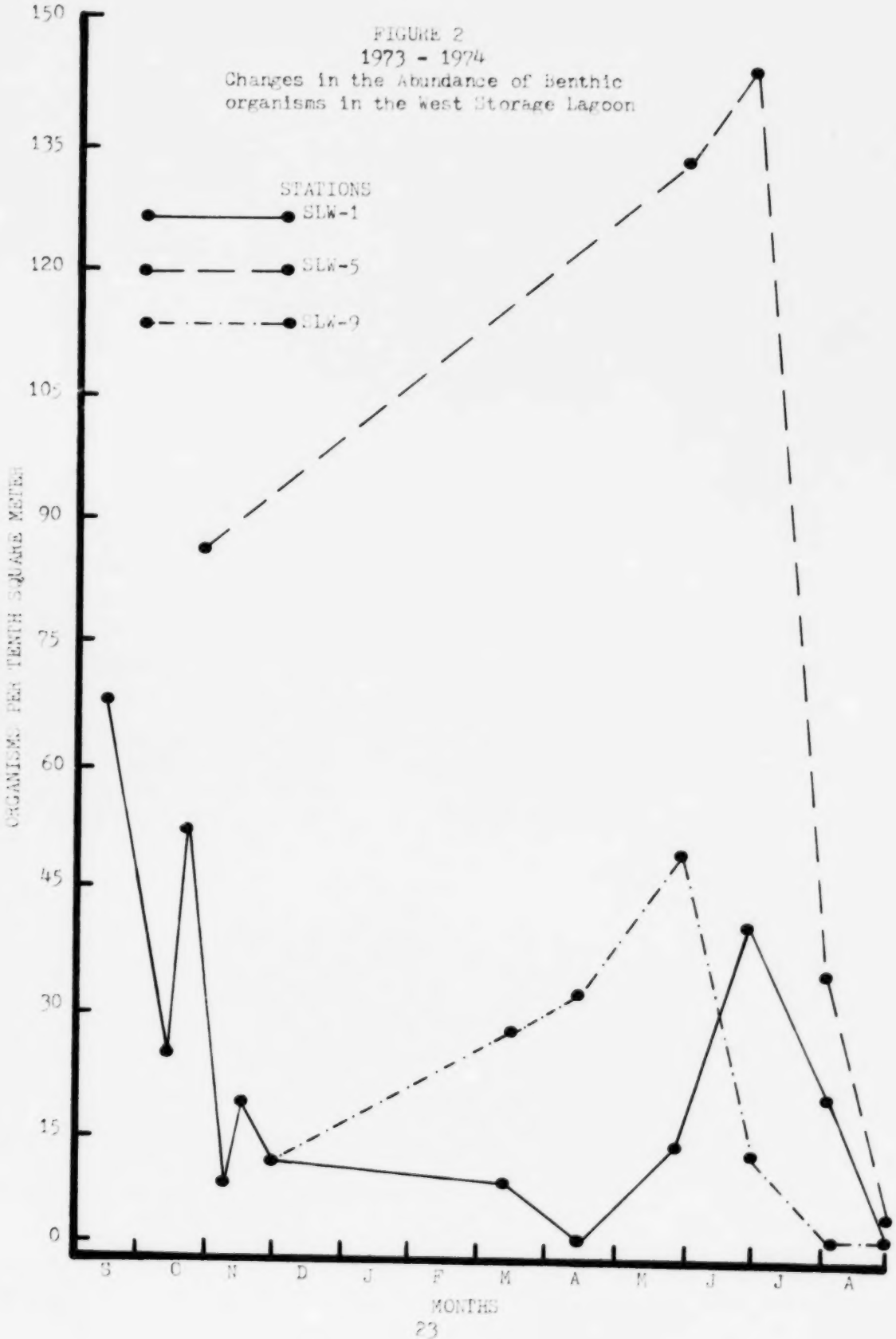
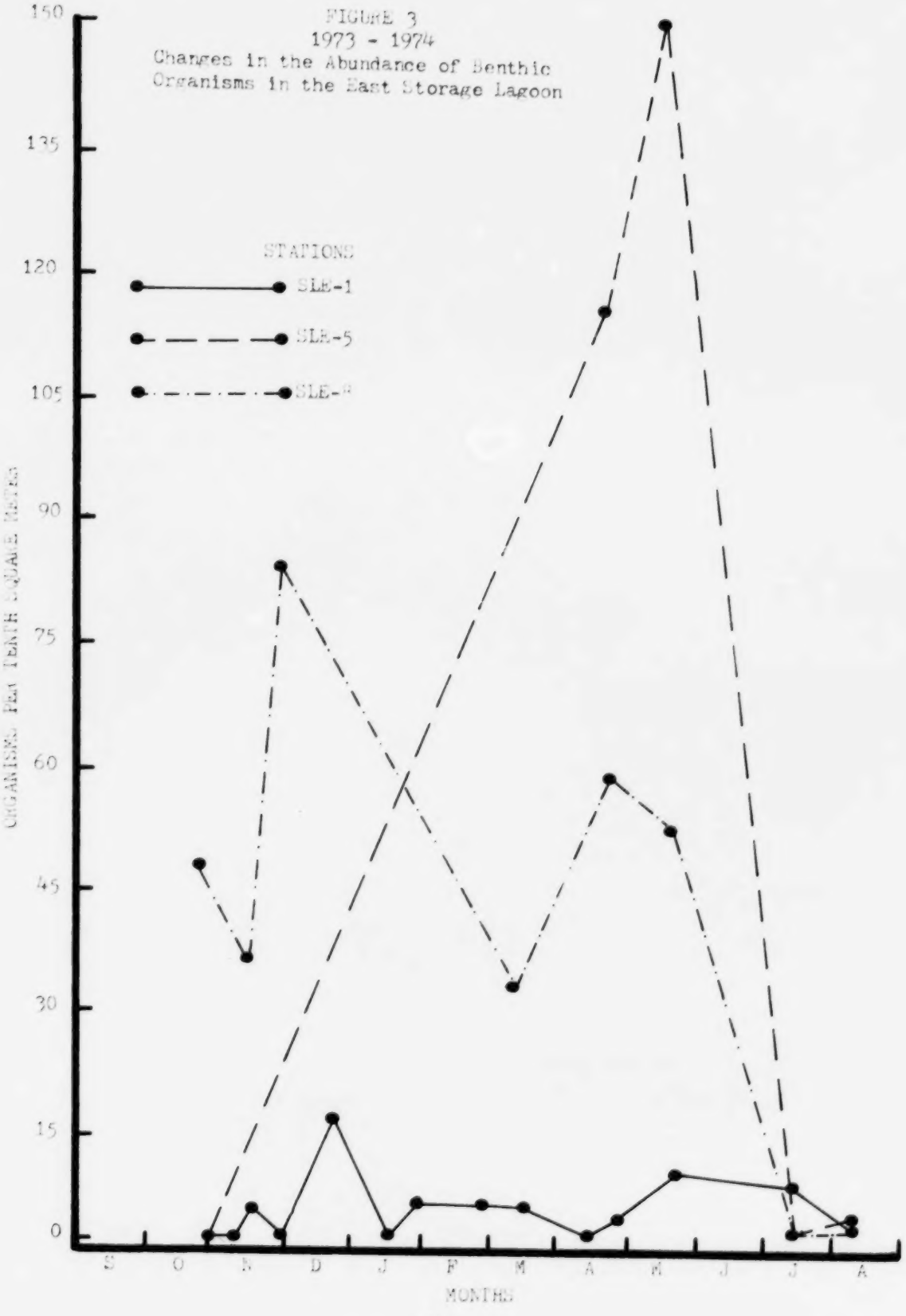


FIGURE 3
1973 - 1974
Changes in the Abundance of Benthic Organisms in the East Storage Lagoon



Organic pollution usually results in the depression of diversity, $\bar{d}$, in the biotic community, while relatively undisturbed environments have a higher diversity index. Aquatic ecosystems without environmental perturbations usually support communities having large numbers of species with no individual species present in overwhelming abundance. Thus if all individuals belonged to the same species, the diversity would be minimal, while if each individual belonged to a separate species, the diversity would be maximal. Wilhm (1970) and Wilhm and Dorris (1968) report that values for $\bar{d}$ of less than 1 are usually obtained in heavily polluted aquatic environments, values between 1 and 3 in areas of moderate pollution, and values above 3 in unpolluted waters.

The diversity indices calculated for each station indicate that station SLW-9 is heavily polluted, while SLE-5, SLW-1 and SLW-5 are moderately to heavily polluted, and SLE-9 is only moderately polluted to unpolluted. This is not borne out, however, by the other data gathered during this investigation or by knowledge of the source of water in each lagoon. The East Lagoon received semi-treated wastewater while the West Lagoon received seepage water and had a much lower BOD, TOC, and nutrient concentration than did the East Lagoon.

Equitability, e, is calculated by evaluating the component of diversity which is due to the distribution of individuals within the species. This index is reported to be more sensitive than $\bar{d}$, and in fact very sensitive to even slight levels of degradation (Weber, 1973). Its range is normally from 0 to 1. Organic wastes reduce equitability below 0.5 and generally in the range of 0.0 to 0.3. Values between 0.6 and 0.8 are indicative of water not affected by oxygen demanding waste. Since the equitability values calculated for the lagoons were all above 0.5, this indicates that the stations are not organically polluted. Thus the equitability values are not in agreement with the calculated diversity values, nor are they in agreement with the other parameters tested.

It may not be appropriate in this study to calculate diversity and equitability, and compare the results to historical work, because almost all of the reported uses of $\bar{d}$ and e have been in studies with over 100 in-

dividuals per sample, in established lotic communities, and in communities receiving predominantly organic wastes. These conditions are not met in this investigation. The Muskegon Lagoons receive more industrial waste, especially from a paper mill, than municipal waste. These lagoons also represent a new aquatic environment. They were man-made and were covered with terrestial vegetation prior to this study. From the beginning, the East Lagoon has been a heavily stressed aquatic environment. Colonization of the benthic community may take much longer than for the development of the planktonic community, due in part to the much longer generation time in the benthic macroinvertebrates than in the plankton.

ZOOPLANKTON

The zooplankton data are summarized in Tables 6 and 7 and also in Figures 4-12.

Although there was considerable variability through time in regard to the mean number of organisms per liter in each lagoon, and in the dominant group, the number of zooplankton per liter consistently remained higher in the nutrient and organically richer East Lagoon than in the West Lagoon (Table 6). The mean in the East Lagoon ranged from a low of 6.3 organisms per liter on 16 November 1973 to a high of 132.3 on 9 August 1974, while the mean in the West Lagoon ranged from 5.9 organisms per liter, also on 16 November 1973 to a high of 57.3 on 15 August 1974. The greater number of zooplankton in the nutrient-richer East Lagoon is to be expected, since more eutrophic waters often support higher zooplankton populations than less eutrophic waters (Schelske and Roth, 1973). It is believed that this is partly due to the higher food supply, namely phytoplankton, in more eutrophic waters. Davis (1958) feels that the zooplankton depend more on phytoplankton than upon nonliving organic matter, even in organically rich waters. It has not been determined if this is true in the Muskegon Lagoons. The zooplankton pulses (Figs. 5 and 6) do not appear to correspond to the phytoplankton pulses, and the phytoplankton counts in the West Lagoon were higher, but the zooplankton counts lower, than those in the East Lagoon. This disparity could be due in part to the methods used to enumerate the zooplankton and the phytoplankton since

TABLE 6

Comparison of Zooplankton counts (organisms/liter) in the East and in the West Lagoons. Data are given as the mean ± one standard deviation, followed by the dominant taxa and, in parentheses, the percentage of all zooplankton in the indicated collection.

DATE	LAGOON	
	EAST	WEST
10-26-73	37 ± 24 Daphnia (52.7%)	9.8 ± 2.9 Cyclopoid Copepods, unidentified genera ** (74.1)
11- 9-73	9.9 ± * Daphnia (68.7%)	6.6 ± 1.6 Cyclopoid Copepods, unidentified genera ** (34.6%) Cyclops excilis (24.0%) Daphnia (21.0%)
11-16-73	6.3 ± * Daphnia (65.1%)	5.9 ± * Unidentified Rotifer (30.5%) Chydorus sphaericus (23.7%) Filinia longiseta (23.7%)
5-14-74		13 ± 5.9 Daphnia (47.2%) Cyclops (40.8%)
5-21-74	95 ± 110 Daphnia (92.3%)	
5-28-74		32 ± 13 Daphnia (84.3%)
6-11-74	42 ± 7.1 Daphnia (52.2%) Cyclopoid Copepods (44.7%)	

* = only one station sampled
** = see description following this table

TABLE 6 CONCLUDED

DATE	LAGOON	
	EAST	WEST
6-28-74		22 ± 13 Daphnia (37.6%) Diaptomus (36.9%)
7-12-74	130 ± 38 Cyclopoid Copepods (100%)	
7-19-74		
7-26-74	58 ± 14 Cyclopoid Copepods (100%) Cyclops vernalis (46.4%)	19 ± 5.4 Diaptomus (66.1%)
8- 2-74		
8- 9-74	130 ± 40 Cyclopoid Copepods (99.2%) Cyclops vernalis (31.6%)	16 ± 5.8 Diaptomus (56.8%)
8-15-74		
8-20-74	130 ± 30 Cyclopoid Copepods (97.5%) Cyclops vernalis (25.0%)	57 ± 23 Diaptomus (61.2%)
8-29-74		56 ± 14 Daphnia (53.4%)

FIGURE 4

Key for unidentified cyclopoid copepods

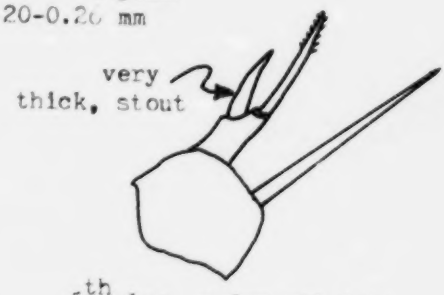
E_6 and E_7 : E_6 has 6 segmented antenna, E_7 has 7 segmented antenna

The rest of the characteristics are identical

Legs 1-3 have 2 segmented rami

Leg 4 has only a 1 segmented rami, and therefore doesn't fit key

Size: head to caudal rami is 0.41-.50mm
terminal setea is 0.20-0.26 mm



5^{th} leg, under oil lens

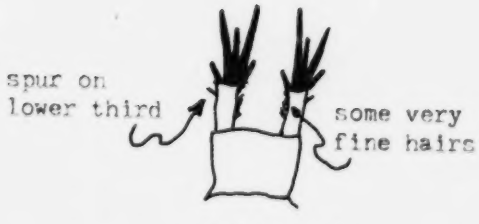
B_8 and B_9 : B_8 has 8 segmented antenna, B_9 has 9 segmented antenna

The rest of the characteristics are identical

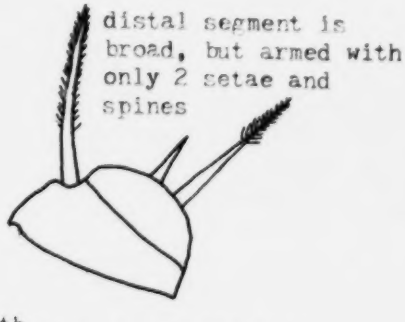
Legs 1-3 have 2 segmented rami

Leg 4 has a 1 segmented rami, and therefore doesn't fit key

Size: head to caucal rami is
0.65-0.75 mm and terminal
setea is 0.26-0.30 mm



caudal rami



5^{th} leg, under oil lens

FIGURE 5

Changes in the abundance of zooplankton in the East Storage Lagoon

1973 - 1974

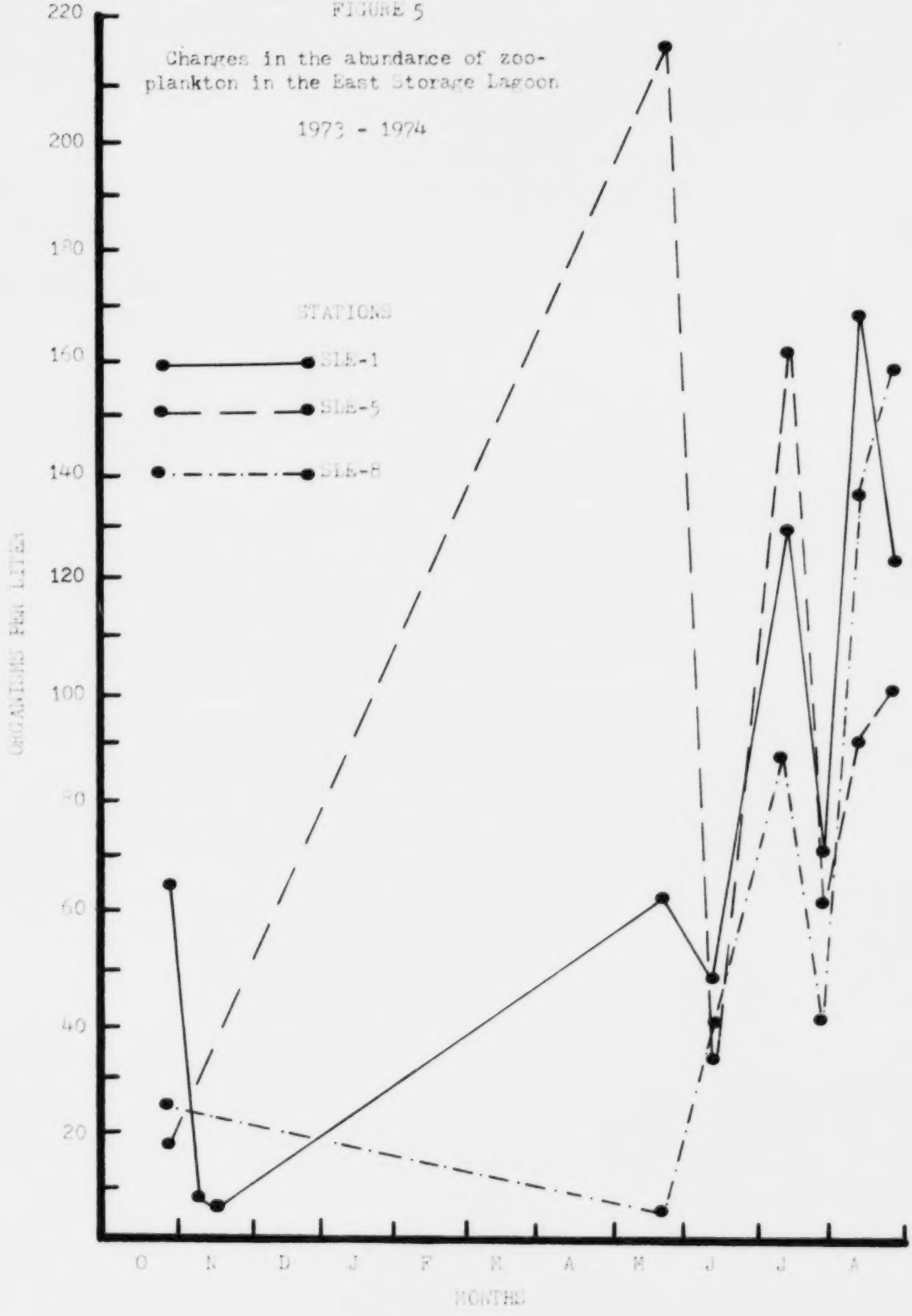
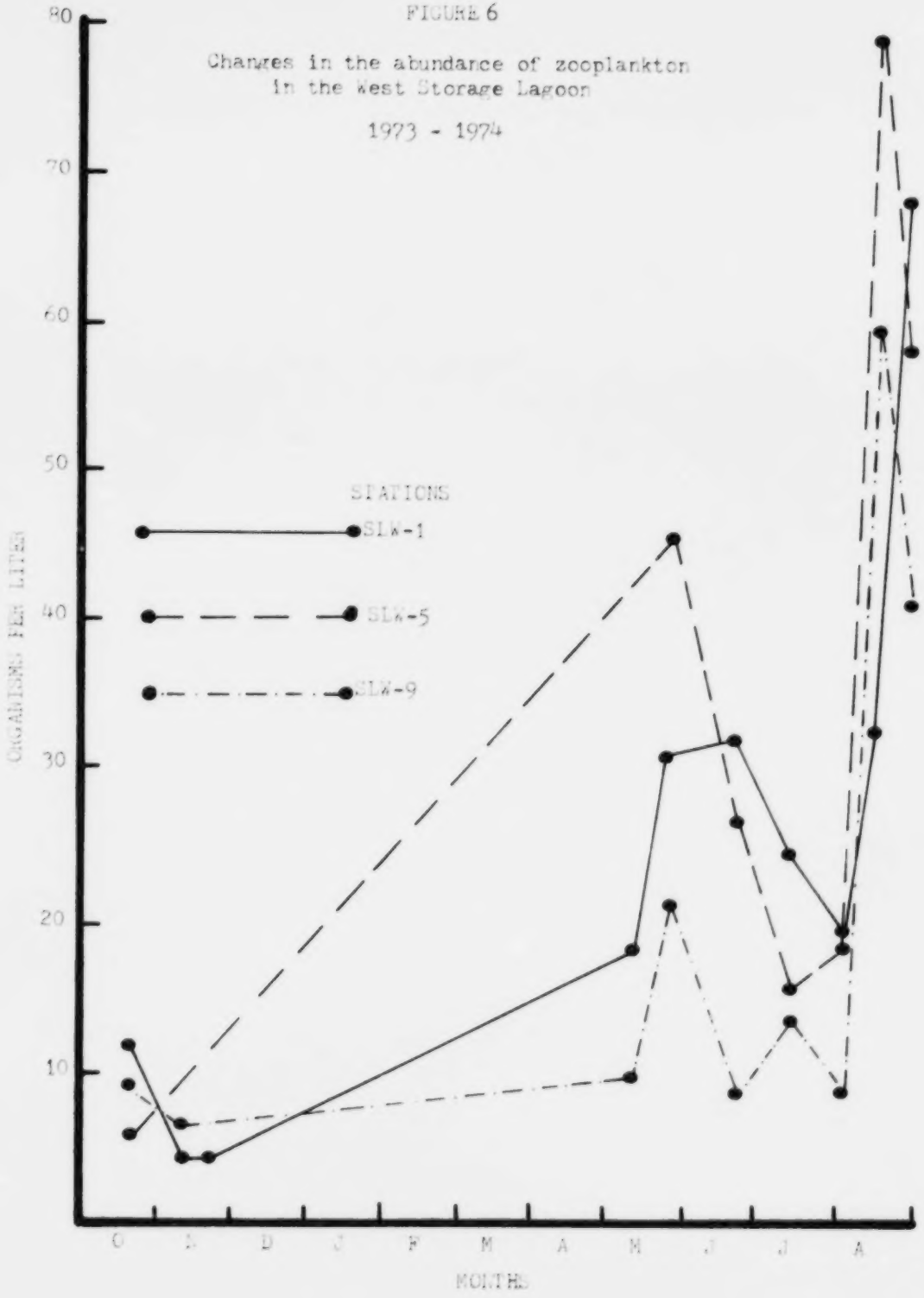


FIGURE 6

Changes in the abundance of zooplankton
in the West Storage Lagoon

1973 - 1974



only numbers were determined and not biomass. Another difficulty in determining a relationship between the zooplankton and the phytoplankton is the difference in the digestibility of the various algae, depending upon the thickness and other properties of the algal cell wall (Hutchinson, 1967). There is also conflicting evidence, however, that phytoplankton do not constitute a controlling or limiting factor with respect to the overall zooplankton population (Reid, 1961; Hutchinson, 1967).

The majority of the zooplankton were crustacean arthropods (Table 7). The class Crustacea, which was represented by 3 orders and 9 genera, accounted for 97.3% of the total zooplankton in the East Lagoon and 98.9% in the West Lagoon. On the order and genus levels, however, the similarities between lagoons disappear.

Cyclopoid copepods dominated the zooplankton in the wastewater East Lagoon, representing 75.2% of the population. They comprised only a small portion of the total zooplankton population in this lagoon during the early phases of this study, a period when the zooplankton populations were very small. During the summer of 1974, however, they were dominant and accounted for most of the large increase in the number of zooplankton (Fig. 7). Of the ten species of cyclopoid copepods present, Cyclops vernalis was the most common, representing 19.8% of all zooplankton in the East Lagoon.

In the West Lagoon, cyclopoid copepods accounted for only 14.1% and Cyclops vernalis for only 1.9% of the total zooplankton. The percentage of total zooplankton which were comprised of cyclopoid copepods declined in the West Lagoon throughout this study (Fig. 8), a trend opposite the events which occurred in the East Lagoon. The dominant zooplankton in the West Lagoon were the cladocerans, which as 51.2% were more than twice the percentage of cladocerans in the other lagoon (21.6%). Daphnia was the dominant genera in the zooplankton of the seepage water West Lagoon, 41.4%, followed by Diaptomus, 33.6%.

It is important to note that in the wastewater East Lagoon Diaptomus represented only 0.5% of the total zooplankton population. This change from calanoid copepods (Diaptomus) in the West Lagoon to cyclopoid copepods in the East Lagoon corresponds to the general trend for changing

TABLE 7

Percentage Composition and Occurrence of Zooplankton. The first number represents the percentage composition and the second number, in parentheses, represents the percentage occurrence. See text for further details.

TAXA	STATIONS							
	SLE-1	SLE-5	SLE-8	SLA-1	SLA-5	SLA-9	EAST, TOTAL	WEST, TOTAL
No. of samples	9	7	7	10	7	9	23	26
I Arthropoda, Crustacea	95.1 (100.0)	98.3 (100.0)	100.0 (100.0)	98.0 (100.0)	100.0 (100.0)	98.2 (100.0)	97.3	98.9
A. Copepoda, Cyclopoida	76.1 (77.8)	65.1 (100.0)	89.4 (100.0)	17.0 (90.0)	11.3 (100.0)	13.6 (100.0)	75.2	14.1
1. Cyclops	42.8 (66.7)	29.8 (85.7)	43.1 (100.0)	5.7 (60.0)	4.4 (71.4)	5.5 (66.7)	38.1	5.2
a. C. vernalis	24.3 (55.7)	14.7 (85.7)	20.6 (100.0)	1.6 (40.0)	2.2 (71.4)	0.9 (44.4)	19.8	1.9
b. C. excilis	11.0 (44.4)	4.9 (57.1)	10.9 (71.4)	1.0 (40.0)	0.0 (0.0)	2.6 (44.4)	8.7	1.1
c. C. sp.	7.5 (44.4)	10.2 (85.7)	11.6 (71.4)	3.1 (30.0)	1.7 (42.9)	1.9 (33.3)	9.6	2.2
2. Mesocyclops	13.8 (66.7)	10.8 (85.7)	15.4 (85.7)	4.2 (50.0)	4.1 (100.0)	1.4 (66.7)	13.3	3.5

TABLE 7 CONTINUED

TAXA	STATIONS							
	SLE-1	SLE-5	SLE-8	SLW-1	SLW-5	SLW-9	EAST, TOTAL	WEST, TOTAL
a. *M. edax*	6.1 (55.6)	6.8 (85.7)	8.8 (57.1	2.0 (40.0)	2.3 (71.4)	1.4 (66.7)	7.2	2.0
b. *M. dybowskii*	0.6 (11.1)	0.3 (14.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.4	0.0
c. *M.* sp.	7.1 (55.5)	3.7 (85.7)	6.6 (71.4)	2.2 (30.0)	1.8 (71.4)	0.0 (0.0)	5.7	1.5
3. *Paracyclops* sp.	3.7 (44.4)	5.4 (71.4)	9.6 (57.1)	* (10.0)	0.1 (14.3)	0.0 (0.0)	5.9	*
4. Unknown Genera **	15.8 (66.7)	19.0 (85.7)	21.3 (85.7)	7.3 (60.0)	2.7 (28.6)	6.7 (66.7)	17.9	5.4
a. B_9 **	6.8 (55.6)	6.5 (57.2)	4.8 (42.9)	2.2 (30.0)	1.4 (28.6)	1.0 (44.4)	5.5	1.6
b. B_6 **	1.6 (33.3)	2.1 (42.9)	3.8 (57.1)	1.4 (20.0)	0.4 (14.3)	2.4 (33.3)	2.4	1.3
c. B_7 **	7.4 (55.6)	10.4 (85.7)	12.7 (85.7)	3.5 (50.0)	0.9 (28.6)	3.3 (33.3)	10.0	2.5
B. Copepoda, Calanoida								
Diaptomus	1.1 (22.2)	0.1 (14.3)	0.1 (14.3)	24.2 (50.0)	40.4 (85.7)	37.2 (66.7)	0.5	33.6

TABLE 7 CONTINUED

TAXA	STATIONS							
	SLE-1	SLE-5	SLE-8	SLW-1	SLW-5	SLW-9	EAST, TOTAL	WEST, TOTAL
C. Cladocera	17.9 (66.7)	33.2 (57.1)	10.5 (57.1)	56.8 (100.0)	48.3 (100.0)	47.4 (100.0)	21.6	51.2
1. Daphnia spp.	17.6 (66.7)	33.2 (57.1)	10.4 (57.1)	43.9 (90.0)	37.8 (100.0)	42.7 (100.0)	21.5	41.4
2. Bosmina longirostris	0.3 (33.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1	0.0
3. Chydorus sphaericus	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	12.9 (70.0)	10.5 (57.1)	4.6 (55.6)	0.0	9.8
4. Alona sp.	0.0 (0.0)	0.0 (0.0)	* (14.3)	* (10.0)	0.0 (0.0)	0.0 (0.0)	*	*
II Rotifer, Monogononta	4.6 (44.4)	1.6 (14.3)	0.0 (0.0)	1.5 (30.0)	0.0 (0.0)	1.7 (22.2)	2.3	1.1
A. Floima	2.1 (44.4)	0.0 (0.0)	0.0 (0.0)	0.1 (10.0)	0.0 (0.0)	0.7 (11.7)	0.8	0.2
1. Brachionus urceolares	2.1 (24.4)	0.0 (0.0)	0.0 (0.0)	0.1 (10.0)	0.0 (0.0)	0.0 (0.0)	0.8	*
2. Keratella sp.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.7 (11.1)	0.0	0.2

TABLE 7 CONCLUDED

TAXA	STATIONS							
	SLE-1	SLE-5	SLE-8	SLW-1	SLW-5	SLW-9	EAST, TOTAL	WEST, TOTAL
B. Floscullariceae								
Filinia longiseta	2.5 (33.3)	1.6 (14.3)	0.0 (0.0)	0.6 (10.0)	0.0 (0.0)	0.2 (11.2)	1.5	0.3
C. Unidentified	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.1 (20.0)	0.0 (0.0)	0.8 (11.1)	0.0	0.6

* = less than 0.1

** = described in Figure 4

FIGURE 7

Cyclopoid copepods as a percentage of total zooplankton in the East Storage Lagoon

1973 - 1974

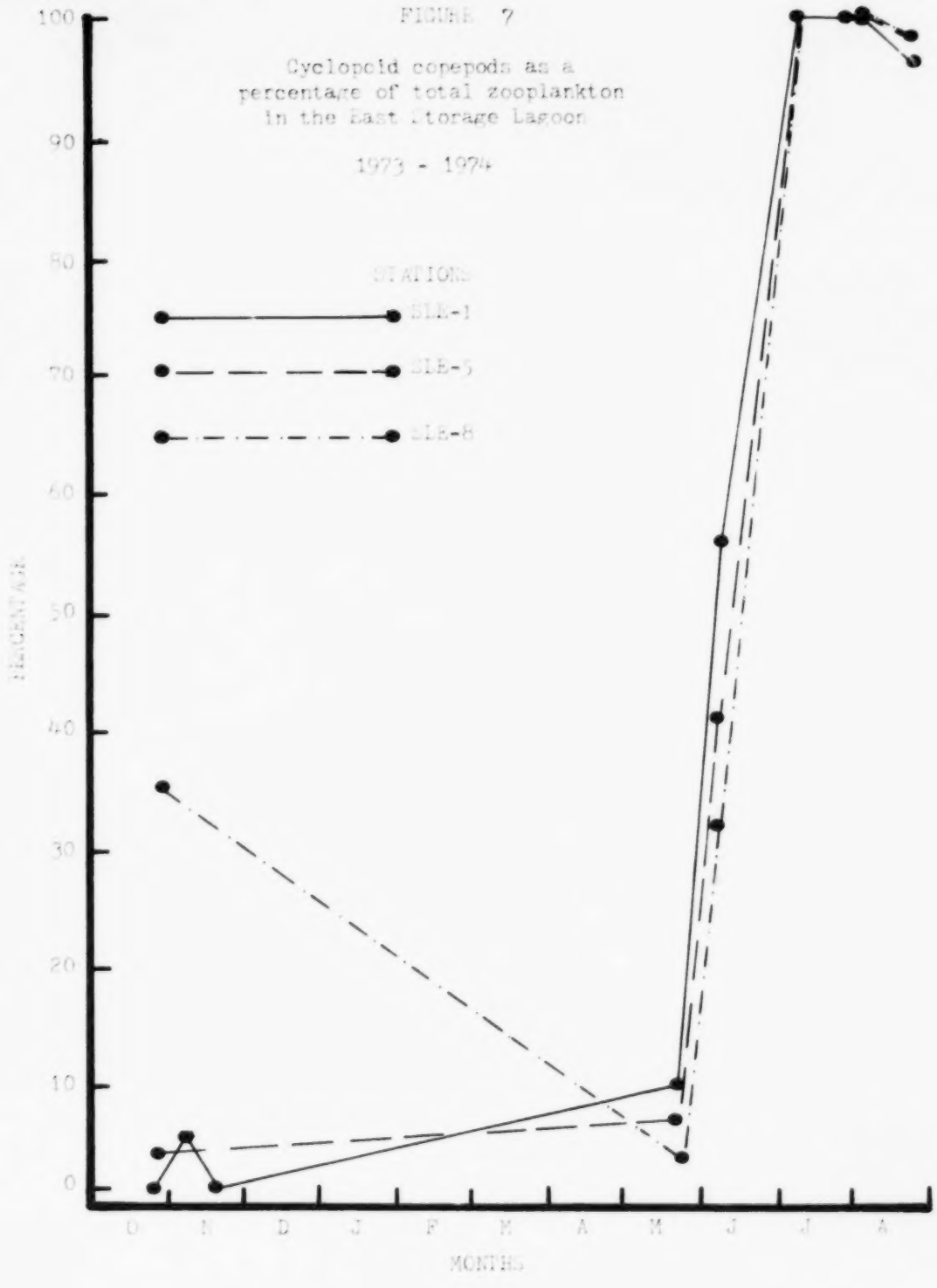


FIGURE 8

Cyclopoid copepods as a percentage of total zooplankton in the West Storage Lagoon

1973 - 1974

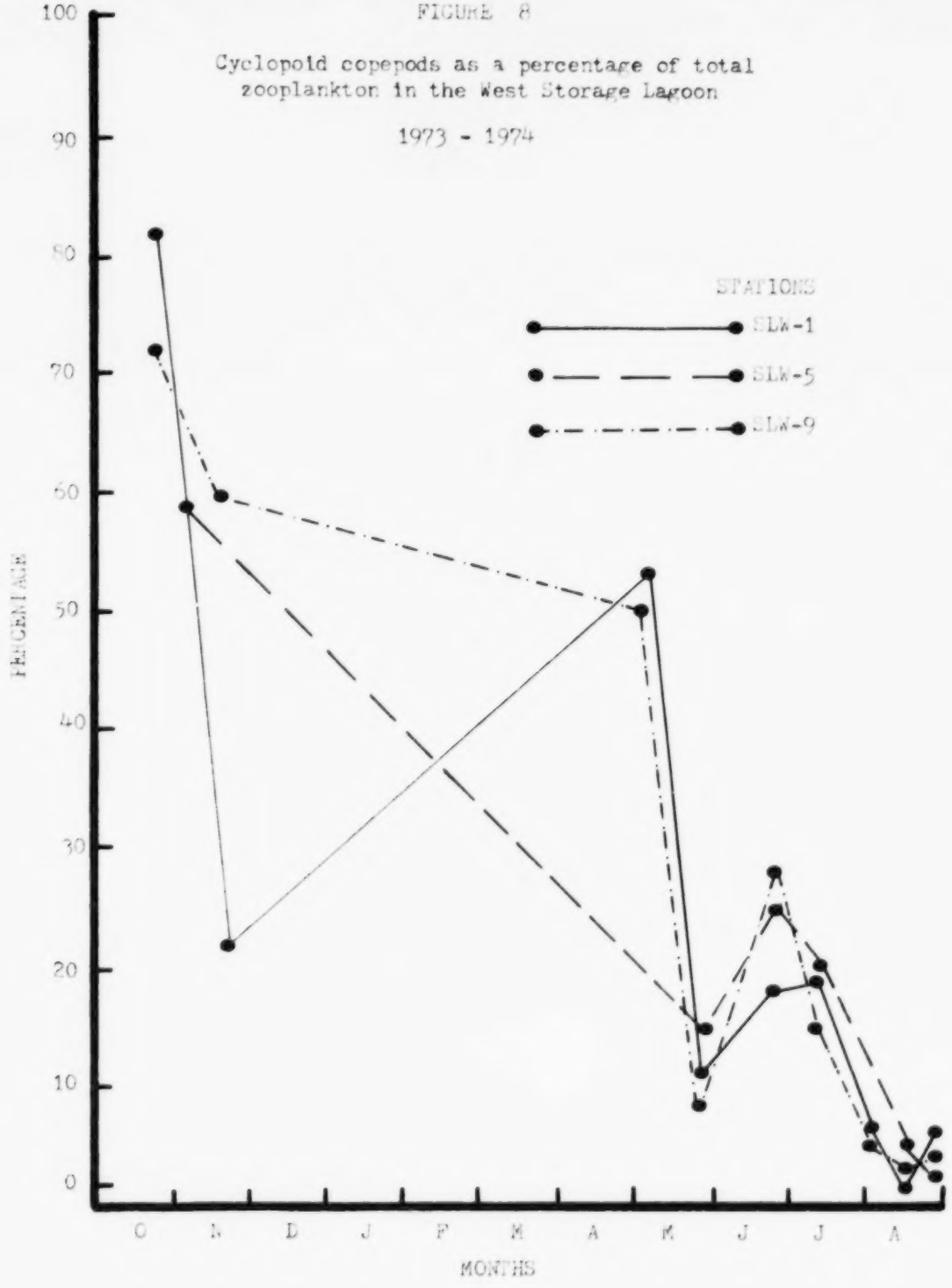


FIGURE 9
1973 - 1974
Cyclops vernalis as a percentage of total zooplankton in the East Storage Lagoon

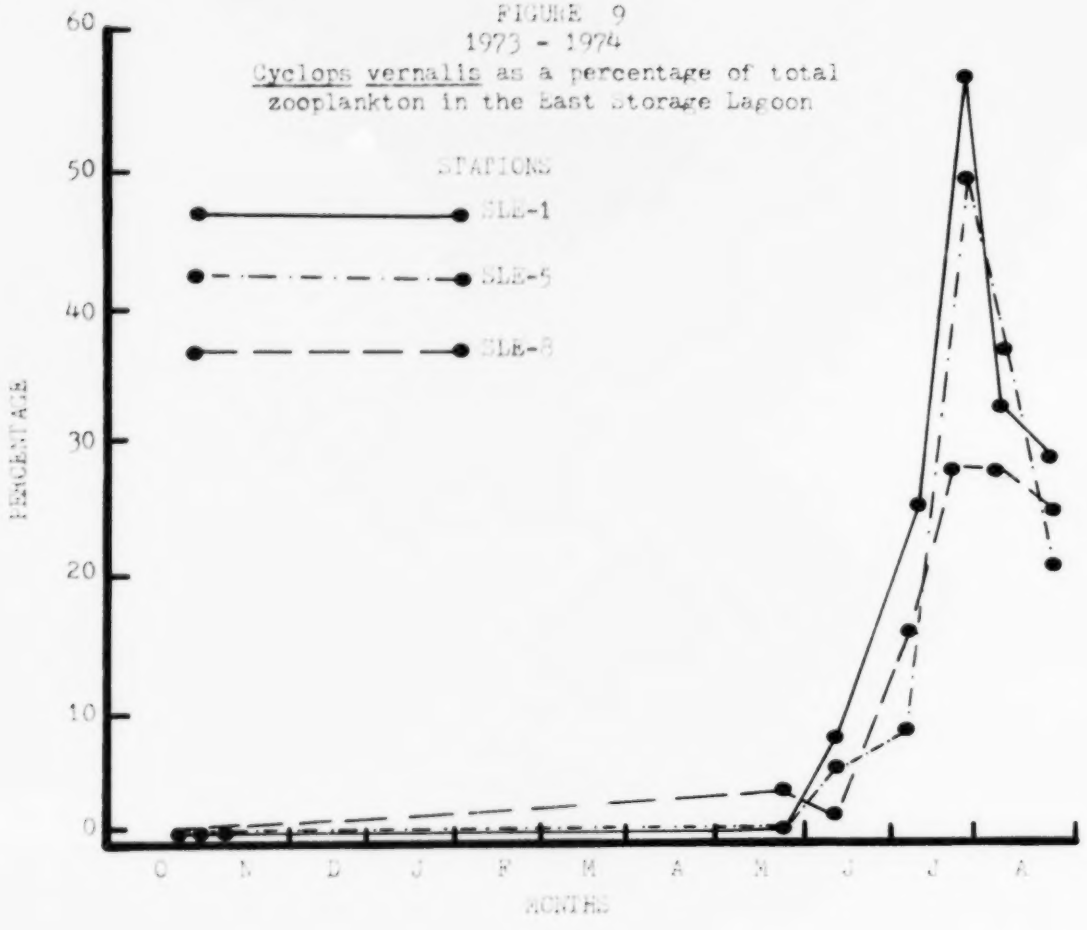


FIGURE 10

Cyclops vernalis as a percentage of total zooplankton in the West Storage Lagoon 1973 - 1974

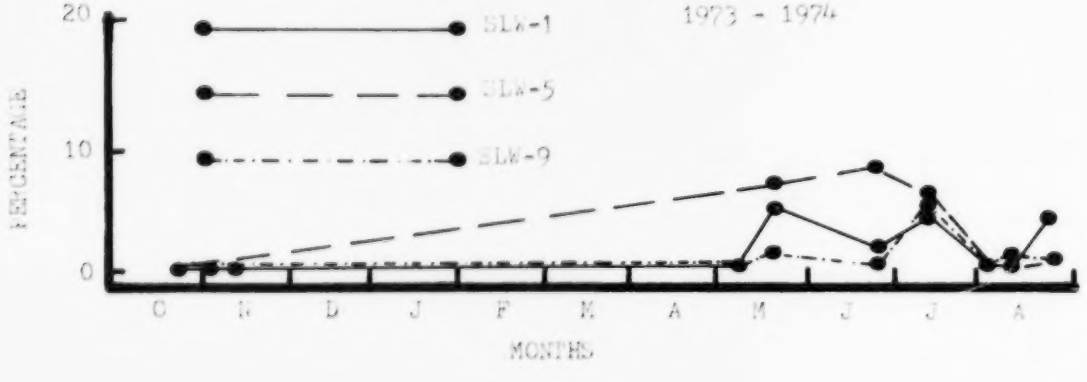


FIGURE 11

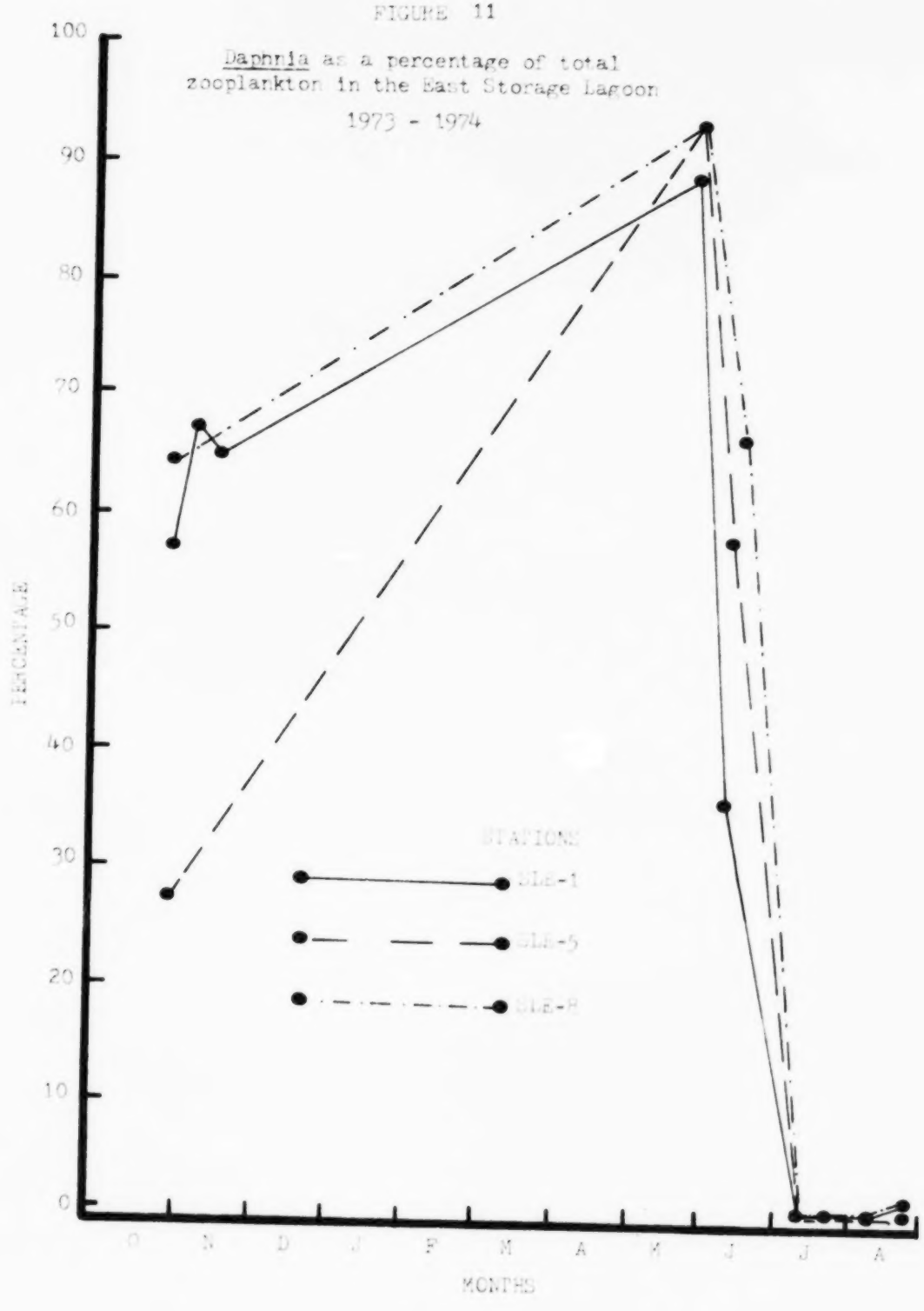
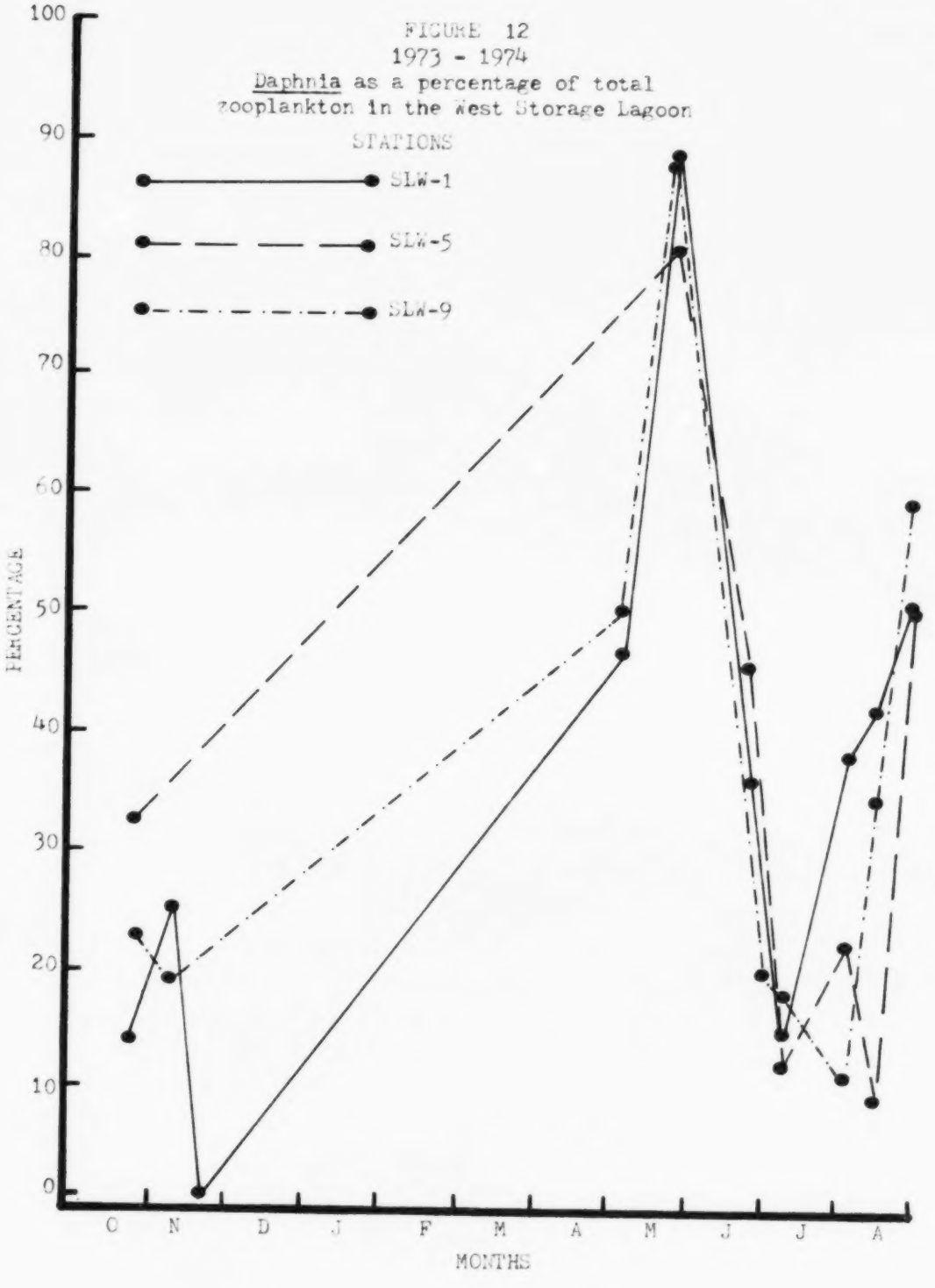

Daphnia as a percentage of total zooplankton in the East Storage Lagoon
1973 - 1974
100
90
80
70
60
50
40
30
20
10
0
PERCENTAGE
STATIONS
SLE-1
SLE-5
SLE-8
O
N
D
J
F
M
A
M
J
J
A
MONTHS

FIGURE 12
1973 - 1974
Daphnia as a percentage of total
zooplankton in the West Storage Lagoon



zooplankton composition as waters go from oligotrophic to eutrophic: the proportion of calanoids decreases while the predominance of cyclopoids increases (Patalas, 1972).

Rotifers were surprisingly scarce, accounting for only 2.3% of the zooplankton in the East Lagoon and 1.0% in the West Lagoon.

The domirance of the zooplankton by copepods (East Lagoon) and cladocerans (West Lagoon) is similar to conditions in the surrounding Great Lakes. From varous studies of Great Lakes zooplankton, Davis (1966) concludes that dominance by either or both of these groups during various seasons of the year is quite characteristic.

Virtually no information concerning zooplankton populations in wastewater lagoons could be found in the literature.

PHYTOPLANKTON AND PROTOZOA

Throughout this paper the abbreviation nr. will be used to denote a species identification which is not positive. If it is not the indicated species, it is a closely related one.

There was a great deal of variability in both time and location in the number as well as the type of protozoa and phytoplankton in the lagoons (Figs. 13 and 14 and Table 8). Due to these large fluctuations in numbers at the different stations, the standard deviation exceeded, or was very close to, the mean number of organisms on 5 out of the 19 sampling dates in the East Lagoon and on 3 out of 19 in the West Lagoon. On 21 December 1973 there were 1,555.7 phytoplankton and protozoan organisms per ml at SLE-1, but only 55.6 at SLE-8, resulting in a mean of 805.6 and a standard deviation of 1060.7. The two major species on this date at SLE-1 (Chlorella nr. vulgaris and Chlamydomonas sp.) were the only two species present at SLE-8. On the next sampling date, 2 January 1974, a bloom of Chlorella nr. vulgaris at SLW-1 but not at SLW-9 accounted for 10,777.7 organisms per ml at SLW-1 but only 847.7 per ml at SLW-9, resulting in a mean of 5812.6 ± 7021.8. A similar condition occurred on 13 March 1974 and also

FIGURE 13
1973 - 1974

Changes in the abundance of Plankton and Protozoans in the East Storage Lagoon (Graph is on 4-cycle semi-logarithmic paper).

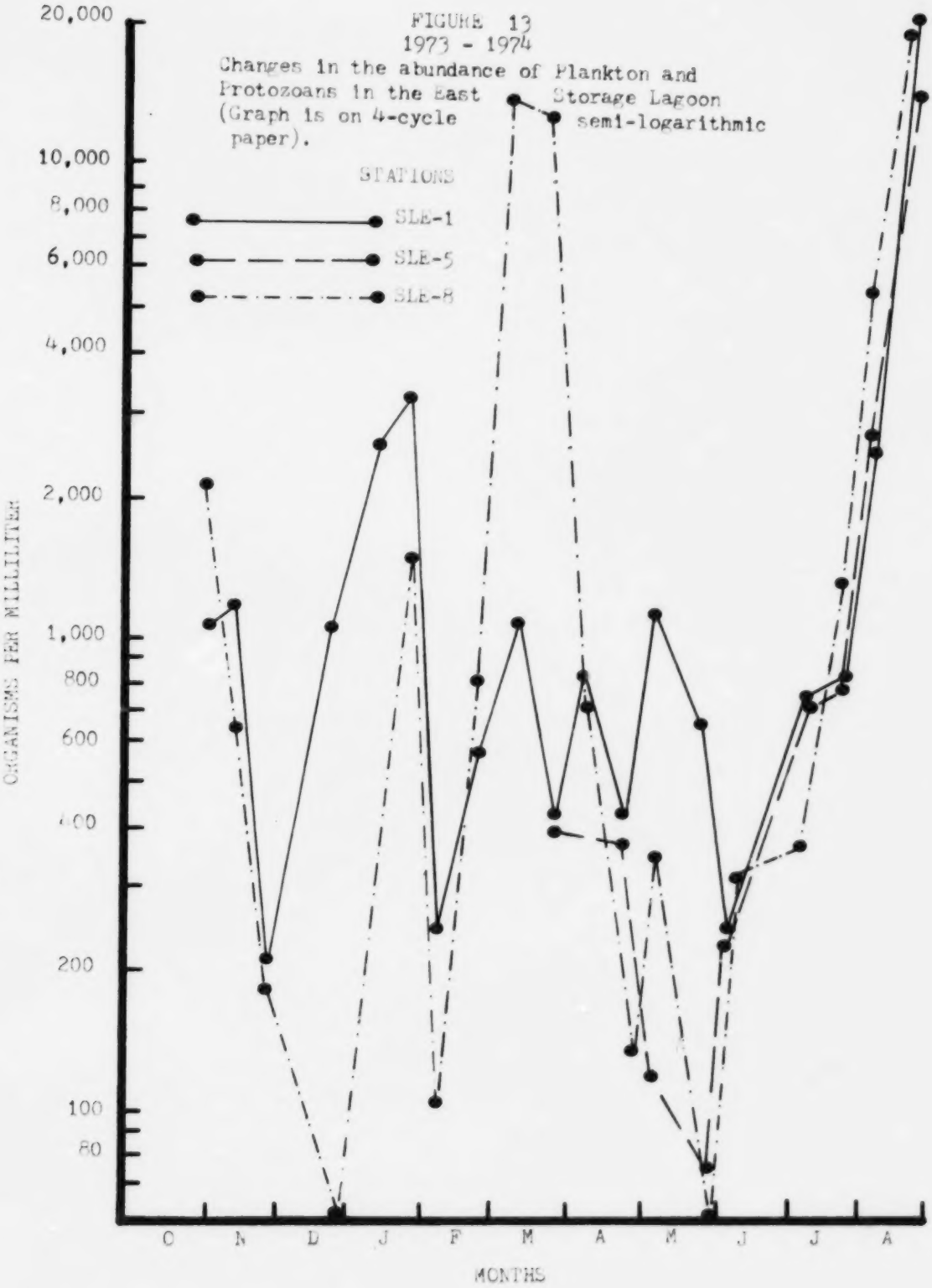


FIGURE 14
1973 - 1974

Changes in the abundance of plankton and protozoans in the West Storage Lagoon (Graph is on 4 cycle semi-logarithmic paper).

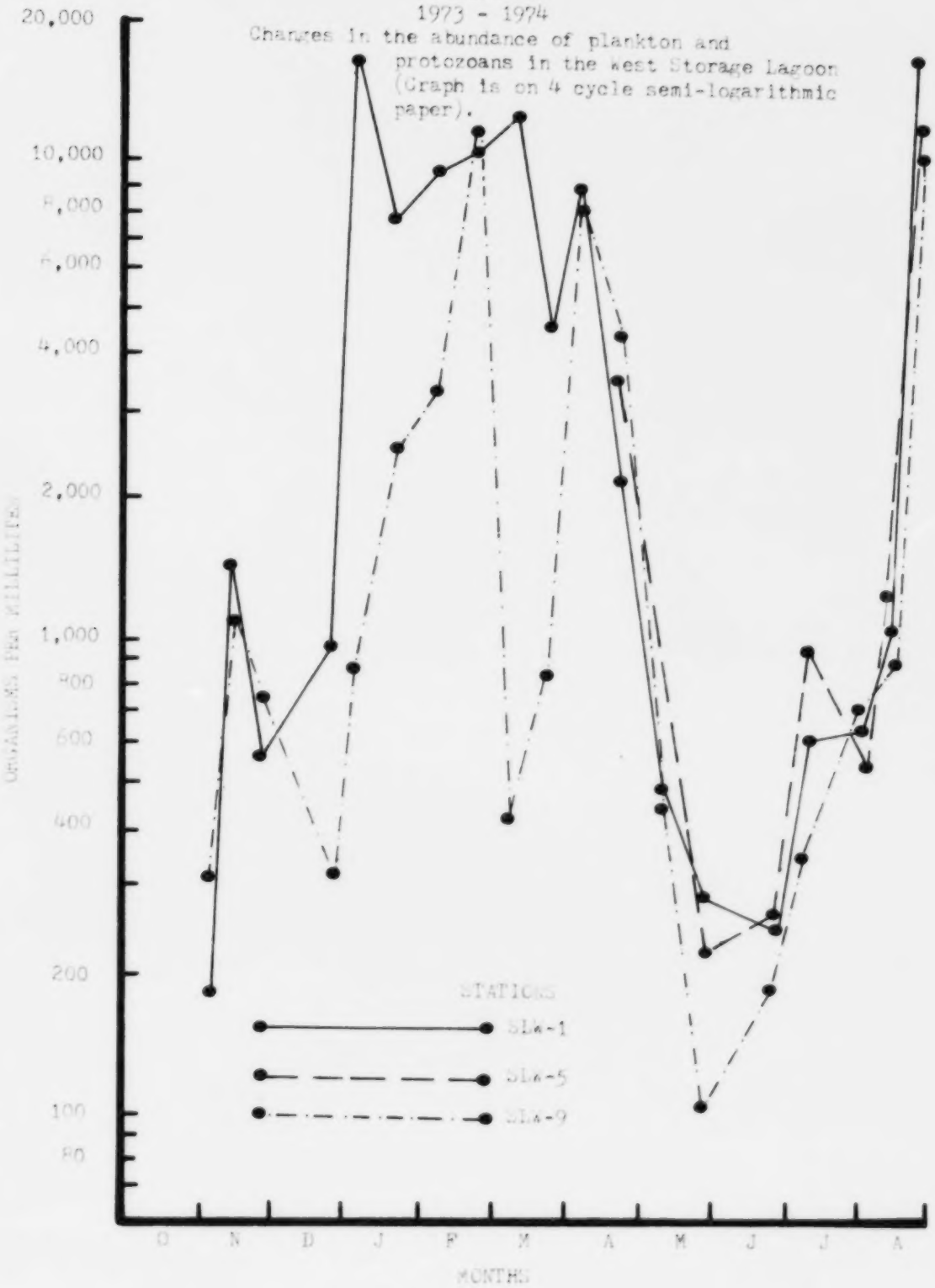


TABLE 8

Comparison of Phytoplankton and Protozoan counts (Organisms/ml) in the East and West Lagoons. Data are given as the mean ± one standard deviation, followed by the principal taxa and, in parenthesis, the taxa's percentage of the mean.

DATE	LAGOON					
	EAST			WEST		
11- 9-73	1600 ± 700	Chlorella nr. pyrenoidosa	(59.1%)	260 ± 110	Bodo sp.	(62.1%)
11-16-73	900 ± 370	Bodo sp.	(45.3%)	1300 ± 160	Bodo sp.	(59.5%)
11-30-73	200 ± 9.8	Melosira nr. granulata	(31.4%)	680 ± 120	Chlorella nr. vulgaris	(56.1%)
12-21-73	800 ± 1100	Chlorella nr. vulgaris	(50.9%)	650 ± 480	Chlamydomonas sp.	(42.9%)
		Chlamydomonas sp.	(38.8%)			
1- 2-74				5800 ± 7000	Chlorella nr. vulgaris	(78.3%)
1-16-74	2000 ± 970	Chlorella nr. vulgaris	(76.0%)			
1-30-74	2400 ± 1000	Chlamydomonas sp.	(69.3%)	5200 ± 3700	Chlamydomonas sp.	(83.3%)
2-13-74	180 ± 120	Chlamydomonas sp.	(36.5%)	5400 ± 3700	Chlorella nr. vulgaris	(94.5%)

TABLE 8 CONTINUED

DATE	LAGOON	
	EAST	WEST
2-27-74	720 ± 170 Chlorella nr. pyrenoidosa (63.7%)	10000 ± 620 Chlorella nr. vulgaris (84.9%)
3-13-74	7900 ± 9400 Chlorella nr. pyrenoidosa (89.0%)	6600 ± 7300 Chlorella nr. vulgaris (95.7%)
3-29-74	9400 ± 8000 Chlorella nr. pyrenoidosa (78.8%)	2700 ± 2400 Chlorella nr. vulgaris (83.4%)
4-12-74	790 ± 110 Chlamydomonas sp. (39.5%) Chlorella nr. pyrenoidosa (23.4%)	8300 ± 1600 Chlorella nr. vulgaris (91.7%)
4-26-74	320 ± 180 Chlamydomonas sp. (57.5%)	3300 ± 1200 Chlorella nr. vulgaris (89.0%)
5- 7-74	540 ± 500 Chlamydomonas sp. (43.3%) Golenkina paucispina (20.2%)	
5-14-74		480 ± 110 Cyclotella nr. meneghiniana (18.7%) Euglena sp. (18.0%)
5-21-74	250 ± 320 Trachelomonas sp. (49.0%)	
5-28-74		200 ± 136 Glaucoma sp. (39.0%)

TABLE 8 CONTINUED

DATE	LAGOON	
	EAST	WEST
6-11-74	270 ± 120 *Vorticella* sp. (23.7%) *Trachelomonas* sp. (19.9%)	
6-28-74		240 ± 61 *Phacus* sp. (17.2%) *Chroomonas* nr. *nordstedtii* (11.7%) *Chlamydomonas* sp. (11.3%)
7-12-74	620 ± 200 *Glaucoma* sp. (31.2%)	
7-19-74		630 ± 270 *Chlorella* nr. *pyrenoidosoa* (32.3%) *Anabaena constricta* (16.3%)
7-26-74	980 ± 210 *Cryptomonas* nr. *ovata* (33.3%)	
8- 2-74		630 ± 140 *Chlorella* nr. *vulgaris* (32.7%)

TABLE 8 CONCLUDED

DATE	LAGOON	
	EAST	WEST
8- 9-74	3700 ± 1700 Cryptomonas nr. ovata (20.0%) Chlorella nr. vulgaris (9.6%) Ankistrodesmus sp. (9.6%) Chlamydomonas sp. (9.0%)	
8-15-74		1100 ± 120 Chlorella nr. pyrenoidosa (45.3%)
8-20-74	19000 ± 5000 Stephanodiscus nr. invisatatus (30.9%)	
8-29-74		13000 ± 3100 Aphanizomenon flos-aquae (56%)

on 29 March 1974, when a bloom of Chlorella nr. vulgaris at SLW-1 but not at SLW-9 resulted in the standard deviation exceeding or nearly exceeding the mean. A similar situation occurred in the East Lagoon on these dates due to a bloom of Chlorella nr. pyrenoidosa at SLE-8 but not at SLE-1.

In May the standard deviation again exceeded or nearly exceeded the mean number of organisms in the East Lagoon. On 7 May 1974 and again on 21 May 1974 this phenomena was not, however, due to a bloom of any one organism but rather to a general increase in several of the organisms at only one station. Due to higher numbers of Chlamydomonas spp., Golenkina paucispina and Glaucoma spp. at SLW-1 on 7 May 1974, this station had 1398.9 and 894.9 organisms per ml while SLE-5 had only 110.0 and 124.8 per ml and SLE-8 had only 486.0 and 249.8 per ml. Due to an increase in the number of Trachelomonas, Euglena, and Glaucoma on 21 May 1974 there were 694.4 and 631.9 organisms per ml at SLE-1, but only 13.8 and 34.6 per ml at SLE-8 and 125.2 and 34.7 per ml at SLE-5.

The phytoplankton and protozoan population in both lagoons showed some similarities and yet on other occasions the populations were drastically different from one lagoon to the other and even from station to station within the same lagoon. These fluctuations in terms of species composition and numbers are presented in Tables 8-11.

The phytoplankton and protozoan population in both lagoons remained relatively low during the months of May, June, and July, although it was on an upward trend during the latter two months. The highest populations occurred in August in both lagoons, with over 19,000 organisms per ml on 20 August 1974 in the East Lagoon and over 13,000 organisms per ml on 29 August 1974 in the West Lagoon.

Various organisms dominated the overall phytoplankton and protozoan population in each lagoon throughout this investigation. In the West Lagoon Chlorella nr. vulgaris was the dominant organism on 10 out of the 19 sampling dates, but in the East lagoon it was the dominant organism on only 2 out of the 19 sampling dates. Chlamydomonas spp. was the most common form on five occasions in the East Lagoon, followed by Chlorella

nr. pyrenoidosa, dominant on four sampling dates. Each of these forms was dominant on just two occasions in the West Lagoon. Out of the 19 sampling dates, 10 different organisms in the East Lagoon and 8 in the West Lagoon were the dominants on one or more dates.

Chlorella and Chlamydomonas are among the most common algae in other waste-stabilization lagoons, also. Their presence is important, since they are very significant in maintaining a desired oxygen level in the lagoons (Gloyna, 1971).

The percentage composition and occurrence of the phytoplankton and protozoan population, organized by station and group, is presented in Table 9, which also indicates the number of samples obtained from each lagoon and station. Calculations for determining the concentrations of phytoplankton followed the same methodologies as those utilized in the benthos Table 3.

The Chlorophyta clearly dominated the phytoplankton and protozoan population of both lagoons, comprising 55.4% in the East and 67.4% in the West. It is interesting to note that the proportion of the population of the green algae increased from a low of 39.6% at SLE-1 (station nearest to the point of wastewater discharge) to 47.2% at SLE-5, and to 67.9% at SLE-8 (station farthest away from the discharge).

There was a major difference between the percentage of blue- green algae in the East and West Lagoons, with 25.3% of the phytoplankton and protozoan population in the West accounted for by the blue-greens but only 3.0% in the East. It should be noted, however, that the large Cyanophyta bloom (composed of Aphanizomenon flos-aquae) in the West Lagoon on 29 August 1974 accounted for most all of the blue-greens, 93.6%! On this one day 60,277.6 Cyanophyta organisms per ml were counted in the West Lagoon, while on the other 18 sampling dates a combined total of only 4,097.1 blue-green algae were observed. This type of late summer bloom is characteristic of the Cyanophyta and especially of Aphanizomenon, a genus well known for its troublesome blooms in standing bodies of water (Prescott, 1962). It is surprising

TABLE 9

Percentage Composition and Occurrence of Phytoplankton and Protozoans. The first number represents the percentage composition and the second number, in parentheses, represents the percentage occurrence.

TAXA	STATIONS							
	SLE-1	SLE-5	SLE-8	SLW-1	SLW-5	SLW-9	EAST, TOTAL	WEST, TOTAL
No. of samples	32	16	31	30	14	31	79	75
A. Chlorophyta, Chlorophyceae	39.6 (100.0)	47.2 (100.0)	67.9 (100.0)	74.0 (96.7)	42.8 (100.0)	69.3 (96.8)	55.4	67.4
B. Cyanophyta, Myxophyceae	3.5 (68.8)	5.0 (50.0)	2.0 (38.7)	19.9 (53.3)	51.3 (64.3)	21.8 (58.1)	3.0	25.3
C. Chrysophyta, Bacillariophyceae	23.5 (81.2)	25.9 (75.0)	11.2 (67.7)	2.7 (93.3)	3.1 (100.0)	3.3 (83.9)	17.6	2.9
D. Euglenophyta, Euglenophyceae	6.8 (43.8)	5.8 (87.5)	3.2 (58.1)	0.6 (50.0)	1.2 (71.4)	0.6 (35.5)	4.8	0.7
E. Pyrrophyta	0.2 (9.4)	0.4 (25.0)	0.2 (12.9)	* (3.3)	0.0 (0.0)	0.0 (0.0)	0.2	*
F. Protozoa	25.1 (84.4)	13.8 (87.5)	14.7 (74.2)	3.1 (90.0)	1.6 (92.8)	4.8 (100.0)	17.7	3.3
1. Ciliophora	7.2 (71.9)	3.0 (81.2)	1.6 (54.8)	1.0 (63.3)	0.9 (71.4)	1.9 (71.0)	3.6	1.3

TABLE 9 CONCLUDED

TAXA	STATIONS							
	SLE-1	SLE-5	SLE-8	SLW-1	SLW-5	SLW-9	EAST, TOTAL	WEST, TOTAL
2. Mastigophora	16.6 (50.0)	9.2 (62.5)	11.1 (54.8)	2.2 (60.0)	0.6 (78.6)	2.7 (54.8)	12.4	2.0
3. Sarcodina	1.3 (18.8)	1.6 (37.5)	2.0 (25.8)	* (6.7)	* (21.4)	0.1 (16.7)	1.7	*
C. Unidentified Taxa **	1.5 (12.5)	2.0 (25.0)	0.4 (16.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.0	0.0

* = less than 0.1.

** = This taxon appears to be composed of one genus of light colored, spherical organisms, approximately 3-5 microns in diameter.

that the blue-green algae were more common in the seepage water West Lagoon than in the nutrient and organically richer wastewater East Lagoon. It may be, however, that the high amount of available nitrogen in the East Lagoon may eliminate some of the advantage that the nitrogen-fixing blue-green algae have over other algae.

A similar phenomonon occurred with the diatoms, which represented 17.6% of the East Lagoon population and only 2.9% of the phytoplankton and protozoan population in the West Lagoon. A diatom pulse on the last sample date in the East Lagoon, 20 August 1974, accounted for the great majority of diatoms. On this one day a total of 36,756.6 diatoms per ml were observed at the three East Lagoon Stations, while on the other 18 sampling dates a combined total of only 5,057.5 diatoms were observed.

The Euglenophyta, Ciliophora, and Mastigophora were all more common in the nutrient and organically richer East Lagoon than in the seepage water West Lagoon.

In both lagoons the green algae were the most common form during the winter and early spring (Figs. 15 and 16). During this time period, the green algae accounted for the majority of the total phytoplankton and protozoan population and for all of the pulses, while the Euglenophyta were notably absent. From a two-year study of waste-stabilization lagoons, Davis et. al. (1964) concluded that the green algae dominate during the winter months, and several pulses, rather than one peak, can be expected. They also concluded that the Euglenophyta population remains very scant during the winter months and occurs intermittently throughout the rest of the year. These conclusions are supported by the findings in this investigation. Cloyna (1971), however, states that Euglena, together with Chlamydomonas, tend to dominate during cooler weather.

As shown by Tables 10 and 11, the dominant organisms within each phylum or class were comprised of only a few different genera throughout this study. One or more of only four genera were the major Chlorophyta on the 19 sampling dates in the East Lagoon. Chlorella nr. pyrenoidosa,

FIGURE 15

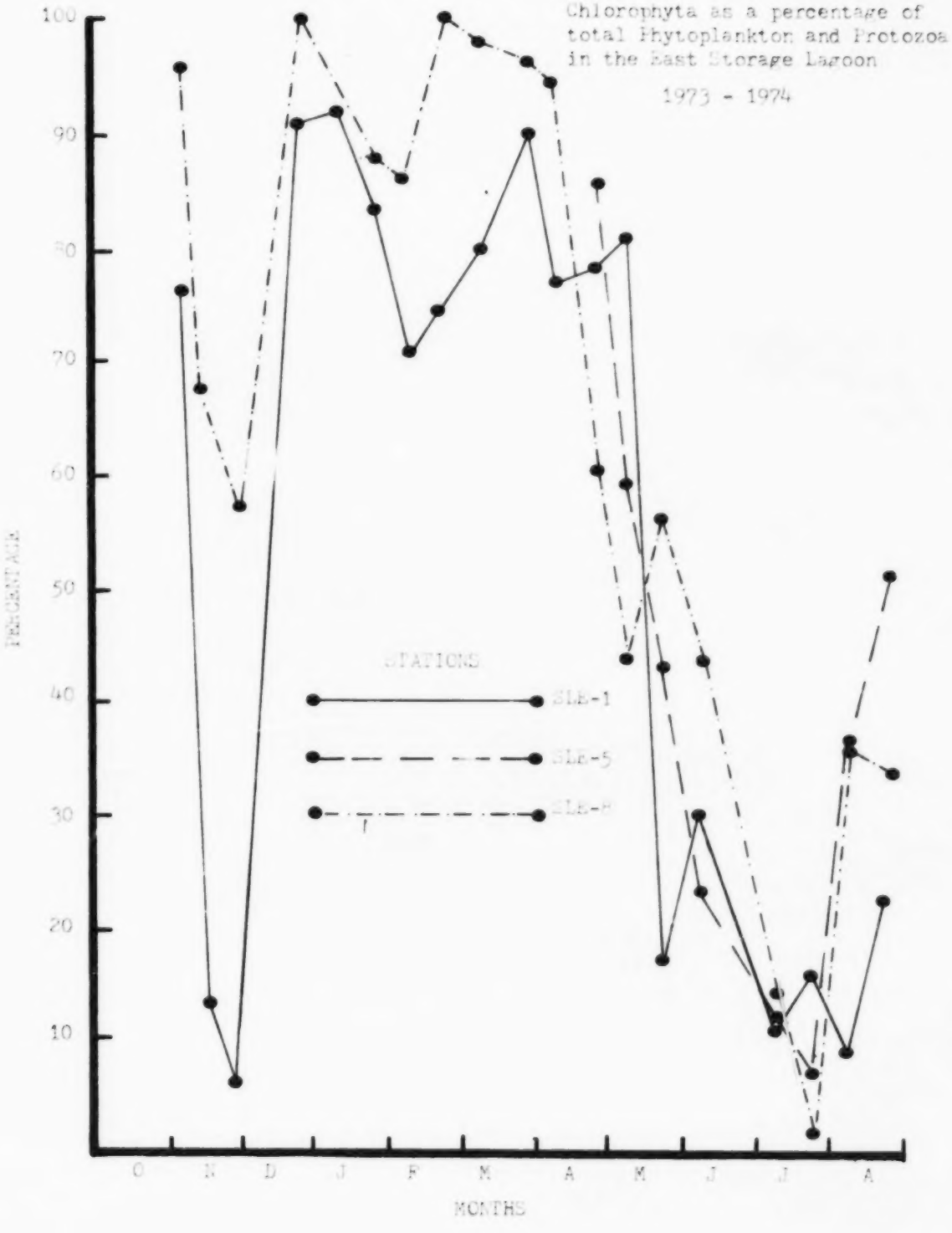

Chlorophyta as a percentage of total Phytoplankton and Protozoa in the East Storage Lagoon
1973 - 1974
PERCENTAGE
100
90
80
70
60
50
40
30
20
10
STATIONS
SLE-1
SLE-5
SLE-8
O
N
D
J
F
M
A
M
J
J
A
MONTHS

FIGURE 16

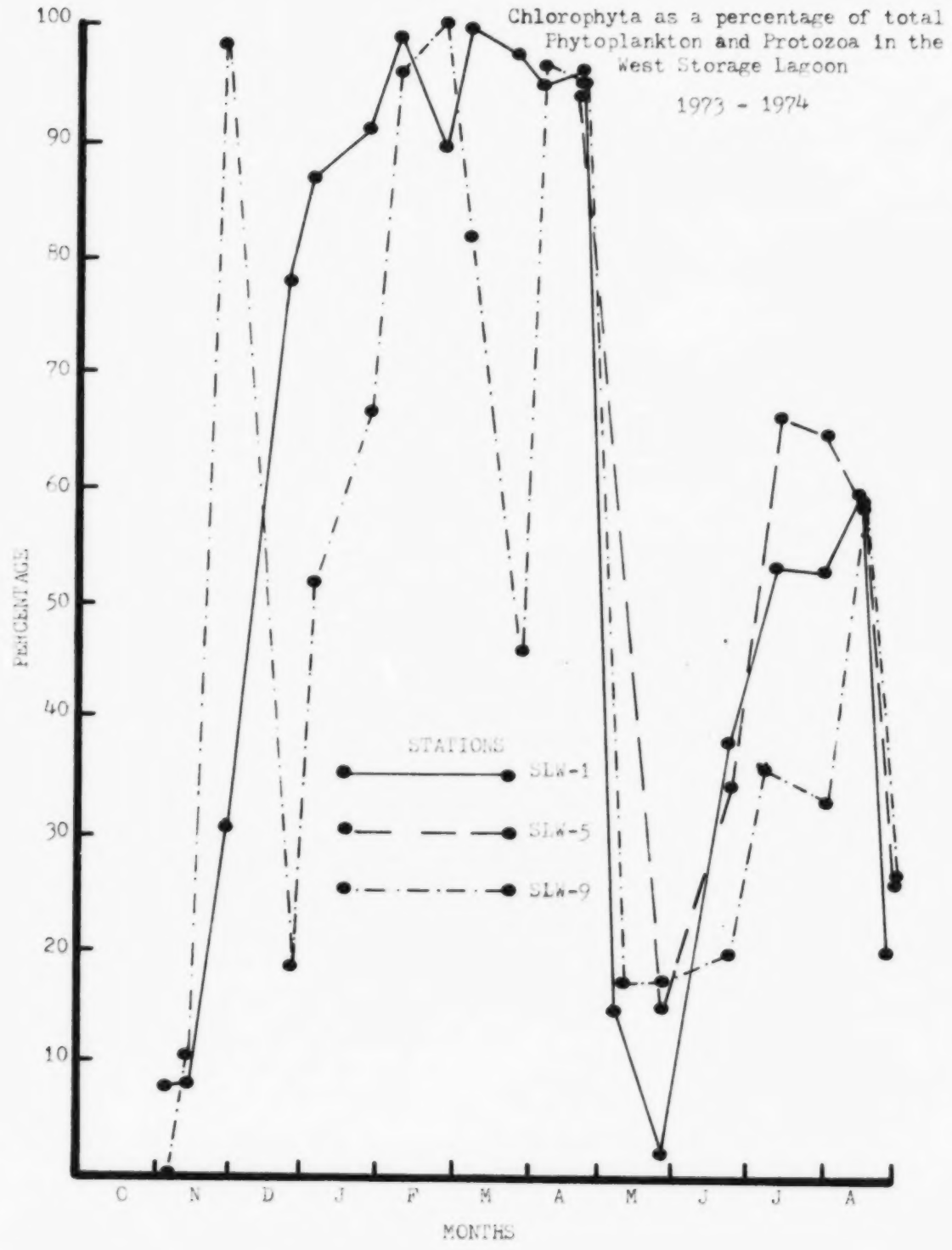

Chlorophyta as a percentage of total Phytoplankton and Protozoa in the West Storage lagoon
1973 - 1974
PERCENTAGE
100
90
80
70
60
50
40
30
20
10
STATIONS
SLW-1
SLW-5
SLW-9
O
N
D
J
F
M
A
M
J
J
A
MONTHS

TABLE 10

Phytoplankton and Protozoan Trends and Dominants in the East Lagoon. Data are given as the mean number of organisms per ml, followed by the percentage of the total number this mean represents, in parentheses, and the major organism(s), arranged in order of decreasing abundance.

KEY TO ABBREVIATIONS

Anab = Anabaena
Ankf = Ankistrodesmus falcutus
Anks = Ankistrodesmus sp.
Chil = Chilomonas nr. paramecium
Chlp = Chlorella nr. pyrenoidosa
Chlv = Chlorella nr. vulgaris
Chrd = Chroococcus dispersus
Chrm = Chroococcus nr. minor
Chrn = Chroomonas nr. nordstedtii
Clam = Chlamydomonas
Cryp = Cryptomonas nr. ovata
Cycl = Cyclotella nr. meneghiniana
Glau = Glaucoma sp.
Gole = Golenkina paucispina
Melg = Melosira granulata
Melv = Melosira nr. varians
Navi = Navicula
Nitz = Nitzschia nr. palae
Nost = Nostoc comminutum
Osci = Oscillatoria
Phac = Phacus spp.
Step = Stephanodiscus nr. invisatatus
Trac = Trachelomonas spp.
Vort = Vorticella sp.

DATE	TOTAL NO./ML	CHLOROPHYTA	CYANOPHYTA	CHRYSOPHYTA	EUGLENOPHYTA	CILIOPHORA	MASTIGOPHORA
11- 9-73	1600	1400 (89.2%) Chlp, Clam	0.0 (0.0%)	150 (9.9%) Melg	14 (0.9%) Phac	0.0 (0.0%)	0.0 (0.0%)
11-16-73	900	300 (32.3%) Chlv, Clam	42 (4.6%) Osci	140 (15.4%) Melg	20 (2.3%) Phac	0.0 (0.0%)	410 (45.4%) Bodo
11-30-73	200	62 (31.0%) Chlv	14 (6.9%) Osci	100 (51.7%) Melg	14 (6.9%) Trac	0.0 (0.0%)	0.0 (0.0%)
12-21-73	800	730 (90.5%) Chlv, Clam	34 (4.3%) Chrm	20 (2.6%) Cycl	0.0 (0.0%)	21 (2.6%) Glau	0.0 (0.0%)

TABLE 10 CONTINUED

DATE	TOTAL NO./ML	CHLOROPHYTA	CYANOPHYTA	CHRYSOPHYTA	EUGLENOPHYTA	CILIOPHORA	MASTIGOPHORA
1-16-74	1900	1800 (93.7%) Chlv	76 (4.0%) Chrm, Chrd	90 (4.7%) Cycl	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
1-30-74	2400	2000 (84.6%) Clam	62 (2.6%) Chrm, Chrd	210 (8.8%) Cycl	0.0 (0.0%)	87 (3.6%) Vort	7.0 (0.3%) Bodo
2-13-74	180	140 (75.0%) Clam	7.0 (3.8%) Chrm	3.5 (1.9%) Cycl	0.0 (0.0%)	21 (11.5%) Vort, Glau	10 (5.8%) Bodo
2-27-74	720	640 (89.3%) Chlp	76 (10.6%) Nost, Chrm	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
3-13-74	7900	7700 (97.6%) Chlp, Clam	10 (0.1%) Csci	0.0 (0.0%)	0.0 (0.0%)	170 (2.2%) Vort, Glau	6.9 (0.1%) Chil
3-29-74	9400	9200 (97.8%) Chlp	51 (0.5%) Chrm, Chrd	37 (0.4%) Navi	0.0 (0.0%)	0.0 (0.0%)	32 (0.3%) Chil
4-12-74	790	670 (85.0%) Clam, Chlp	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	94 (11.9%) Glau, Vort	0.0 (0.0%)
4-26-74	320	260 (79.6%) Clam	2.3 (0.7%) Chrm, Chrd	31 (9.6%) Nitz	0.0 (0.0%)	26 (7.8%) Vort	3.4 (1.1%) Bodo

TABLE 10 CONCLUDED

DATE	TOTAL NO./ML	CHLOROPHYTA	CYANOPHYTA	CHRYSOPHYTA	EUGLENOPHYTA	CILIOPHORA	MASTIGOPHORA
5- 7-74	540	380 (71.5%) Clam, Gole	6.9 (1.3%) Osci	10 (1.9%) Nitz, Melv	47 (8.8%) Trac	53 (9.9%) Glau	33 (6.1%) Chrn, Bodo
5-21-74	260	56 (21.7%) Clam	2.3 (0.9%) Osci, Chrm	21 (8.1%) Melv	130 (52.5%) Trac	40 (15.8%) Glau	2.3 (0.9%) Bodo
6-11-74	270	93 (34.0%) Chlr, Clam	4.6 (1.7%) Chrm	29 (10.6%) Nitz	69 (25.4%) Trac	78 (28.4%) Vert	0.0 (0.0%)
7-12-74	620	74 (11.9%) Clam, Chlr	13 (2.0%) Anab	18 (3.0%) Step	150 (23.4%) Trac, Phac	210 (34.2%) Glau	140 (22.1%) Cryp, Chrn
7-26-74	980	120 (12.8%) Ankf, Clam	57 (5.8%) Anab	21 (2.2%) Step, Cycl	110 (11.5%) Phac, Trac	140 (14.6%) Glau,Vort	430 (44.5%) Cryp
8- 9-74	3700	1300 (35.5%) Chlv, Anks Clam	130 (3.5%) Chrm, Anab	400 (10.9%) Step	240 (6.6%) Phac	180 (4.8%) Glau	1100 (31.3%) Cryp
8-20-74	19000	6500 (34.5%) Chlr, Anks	700 (3.7%) Anab	6100 (32.6%) Step	1100 (6.0%) Trac, Phac	270 (1.5%) Glau	2200 (11.8%) Cryp

TABLE 11

Phytoplankton and Protozoan Trends and Dominants in the West Lagoon. Data are given as the mean number of organisms per ml, followed, in parentheses, by the percentage of the total number this mean represents, and the major organism(s), arranged in order of decreasing abundance.

KEY TO ABBREVIATIONS

Anab = Anabaena
Anac = Anabaena constricta
Anks = Ankistrodesmus sp.
Apha = Aphanocapsa rivularis
Aphz = Aphanizomenon flos-aquae
Chil = Chilomonas nr. paramecium
Chlp = Chlorella nr. pyrenoidosa
Chlv = Chlorella nr. vulgaris
Chrd = Chroococcus dispersus
Chrm = Chroococcus nr. minor
Chrn = Chroomonas nr. nordstedtii
Clam = Chlamydomonas spp.
Cryp = Cryptomonas nr. ovata
Cycl = Cyclotella nr. meneghiniana
Cyum = Cyclidium sp.
Eugl = Euglena spp.
Frag = Fragilaria nr. construens
Glau = Glaucoma spp.
Gole = Golenkina paucispina
Micr = Microcystis aeruginosa
Melg = Melosira granulata
Melv = Melosira nr. varians
Navi = Navicula sp.
Nitz = Nitzschia nr. palae
Phac = Phacus spp.
Scen = Scenedesmus nr. quadricauda var. parvus
Syne = Synedra ulna
Trac = Trachelomonas spp.
Vort = Vorticella sp.

DATE	TOTAL NO./ML	CHLOROPHYTA	CYANOPHYTA	CHRYSOPHYTA	EUGLENOPHYTA	CILIOPHORA	MASTIGOPHORA
11- 9-73	260	7.0 (2.7%) Scen	0.0 (0.0%)	49 (18.9%) Nitz, Melg	27 (10.8%) Phac	0.0 (0.0%)	170 (67.5%) Bodo
11-16-73	1300	120 (8.9%) Chlv	0.0 (0.0%)	70 (5.3%) Nitz	110 (8.4%) Eugl	7.0 (0.5%) Glau	1000 (76.8%) Bodo
11-30-73	680	470 (68.4%) Chlv	0.0 (0.0%)	190 (27.5%) Nitz, Navi	21 (3.1%) Trac	0.0 (0.0%)	7.0 (1.0%) Bodo
12-21-73	650	420 (64.6%) Clam	0.0 (0.0%)	200 (31.4%) Cycl	0.0 (0.0%)	0.0 (0.0%)	27 (4.3%) Bodo

TABLE 11 CONTINUED

DATE	TOTAL NO./ML	CHLOROPHYTA	CYANOPHYTA	CHRYSOPHYTA	EUGLENOPHYTA	CILIOPHORA	MASTIGOPHORA
1- 2-74	5500	4900 (84.0%) Chlv	170 (2.9%) Chrd	180 (3.1%) Cycl	0.0 (0.0%)	0.0 (0.0%)	580 (10.0%) Bodo
1-30-74	5200	4500 (85.0%) Clam	340 (6.5%) Chrd	280 (5.4%) Cycl	0.0 (0.0%)	62 (1.2%) Glau	97 (1.9%) Bodo, Cryp
2-13-74	5400	5300 (97.7%) Chlv	0.0 (0.0%)	28 (0.5%) Melo	0.0 (0.0%)	51 (0.9%) Cyum	46 (0.8%) Bodo, Cryp
2-27-74	11000	10000 (97.5%) Chlv	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	260 (2.5%) Cyum	0.0 (0.0%)
3-13-74	6600	6600 (98.9%) Chlv	0.0 (0.0%)	90 (1.4%) Syne, Navi	0.0 (0.0%)	28 (0.4%) Glau	0.0 (0.0%)
3-29-74	2700	2400 (89.3%) Chlv	17 (0.6%) Anab, Chrm	7.0 (0.2%) Syne	0.0 (0.0%)	260 (9.4%) Glau, Vort	7.0 (0.2%) Cryp
4-12-74	8300	8000 (95.5%) Chlv	66 (0.8%) Chrm, Chrd	280 (3.3%) Frag	0.0 (0.0%)	10 (0.1%) Cyum	3.4 *
4-26-74	3300	3200 (95.5%) Chlv	5.7 (0.2%) Chrm	120 (3.6%) Cycl	12 (0.4%) Trac	2.3 (0.1%) Glau	8.7 (0.3%) Cryp

TABLE 11 CONCLUDED

DATE	TOTAL NO./ML	CHLOROPHYTA	CYANOPHYTA	CHRYSOPHYTA	EUGLENOPHYTA	CILIOPHORA	MASTIGOPHORA
5-14-74	480	73 (15.1%) Chlv	12 (2.5%) Chrm	160 (32.4%) Cycl	94 (19.4%) Eugl	8.7 (1.8%) Cyum	140 (28.8%) Chrn, Cryp
5-28-74	200	20 (9.6%) Cole	0.0 (0.0%)	6.9 (3.4%) Navi	32 (15.8%) Phac	100 (49.7%) Glau	44 (21.5%) Chrn
6-28-74	240	74 (31.4%) Clam, Anks	8.1 (3.4%) Apha, Anab	18 (7.8%) Melv	96 (39.3%) Phac	4.6 (2.0%) Vort, Cyum	45 (19.1%) Chrn, Cryp
7-19-74	630	350 (55.8%) Chlp	190 (30.4%) Anac, Micr	49 (7.7%) Melv, Nitz	6.9 (1.1%) Eugl, Trac	9.2 (1.4%) Vort	18 (2.9%) Cryp
8- 2-74	630	370 (58.6%) Chlv, Chlp	79 (12.4%) Micr	97 (15.3%) Nitz, Melv	15 (2.4%) Trac	58 (9.1%) Vort	3.5 (0.5%) Chil
8-15-74	1100	630 (59.7%) Chlp	160 (15.0%) Aphz, Anab	230 (22.6%) Melv, Melg	14 (1.3%) Eugl	14 (1.3%) Vort	4.6 (0.4%) Chil
8-29-74	13000	3100 (23.6%) Chlp	10000 (75.8%) Aphz	44 (0.3%) Melv	14 (0.1%) Trac	14 (0.1%) Vort	2.3 *

* = Less than 0.1

Chlorella nr. vulgaris and Chlamydomonas spp. were the first dominant green algae. One or more of these two genera (three species) were the principal Chlorophyta from 9 November 1973 through 26 April 1974 and from 21 May 1974 through 12 July 1974. Chlamydomonas sp. and Golenkina paucispina were the most common algae on 7 May 1974. Ankistrodesmus falcutus and Ankistrodesmus sp., together with Chlorella spp. and Chlamydomonas spp. were the major Chlorophyta throughout the remainder of this study.

In the West Lagoon, the composition of the more abundant Chlorophyta was more varied than in the East Lagoon. Scenedesmus nr. quadricauda var. parvus was the dominant green alga on 9 November 1973 and Chlamydomonas spp. or Chlorella nr. vulgaris were the principal green algae from 16 November 1973 through 14 May 1974. Golenkina paucispina was dominant on 28 May 1974, Chlamydomonas spp. and Ankistrodesmus sp. were the most common forms on 28 June 1974, and Chlorella spp. dominated the green algae throughout the rest of this study in the West Lagoon.

Chlorella, Chlamydomonas, and Scenedesmus have been among the first genera of algae to become established in other lagoons also, and they remain typical components of the Chlorophyta throughout the year (Gloyna, 1971). Gloyna (1971) also lists Golenkina as a typical green alga in waste-stabilization lagoons, while both Gloyna (1971) and Davis, et. al. (1964) include Ankistrodesmus as a common representative. The Chlorophyta population of the Muskegon Lagoons appears, therefore, to be quite typical of a wastewater lagoon environment.

The characteristic blue-green algae in the East Lagoon initially consisted of Oscillatoria spp., followed by Chroococcus nr. minor, Chroococcus dispersus and Nostoc commiutum, and in July and August, Anabaena spp.. Chroococcus nr. minor, Chroococcus dispersus, and Anabaena spp. were also dominant in the West Lagoon, along with Aphanocapsa rivularis, Microcystis aeruginosa, and Aphanizomenon flos-aquae. Oscillatoria spp. was never a dominant in the West Lagoon. These species are not as typical of a wastewater lagoon as are the species of Chlorophyta. The only principal blue-green algae Gloyna (1971) listed were Oscillatoria and Anabaena.

while Davis, et. al. (1964), listed four genera dominating the Cyanophyta, Anacystis, Oscillatoria, Phormidium and Spirulina.

With the exception of Chroococcus spp., the principal blue-green algae in the West Lagoon are quite characteristic of eutrophic waters. In a study of Lakes Michigan, Superior, Huron, and Erie, Schelske and Roth (1973) found Aphanizomenon, Microcystis, and Anabaena to be the blue-green genera characteristic of the most eutrophic zones. Hutchinson (1967) listed the same three genera as dominant blue-green algae in eutrophic waters, especially in the temperate zone during the summer months.

The diatom population was generally quite low. In the West Lagoon they were comprised of six genera, Melosira nr. granulata, Melosira nr. varians, Nitzschia nr. palea, Navicula spp., Cyclotella nr. meneghiniana, Synedra ulna and Fragilaria nr. construens. The latter two were never dominant diatoms in the wastewater East Lagoon, but the other four genera, along with Stephanodiscus nr. invisitatus were the dominant diatoms in the East Lagoon. In the literature searched, the only organism mentioned as typical of the diatom population in wastewater lagoons is Nitzschia (Gloyna, 1971). Nitzschia nr. palea, a species found in the Muskegon Lagoons, is the only diatom present out of over 200 organisms which are common in trickling filters (Cooke, 1967).

Melosira granulata and Stephanodiscus spp. are very common representatives of the diatom population in eutrophic waters, with Melosira granulata very rarely occurring in oligotrophic waters. Cyclotella spp., which was often a common diatom in both lagoons, is listed by Hutchinson (1967) as an oligotrophic diatom, a fact which is not in agreement with the findings of this study. Other authors, however, report that Cyclotella meneghiniana is common in waters tending toward eutrophic conditions (Schelske and Roth, 1973).

Phacus, Euglena, and Trachelomonas were the principal Euglenophyta in the seepage-water West Lagoon, while only Phacus and Trachelomonas were the common Euglenophyta in the wastewater East Lagoon. The lack of Euglena as a dominant in the East Lagoon is surprising, for they, along with Phacus, are common dominants of the Euglenophyta in other wastewater lagoons (Gloyna,

1971; Davis, et. al., 1964). Gloyna (1971) describes Euglena as having the highest degree of adaptability to various lagoon conditions of any of the common lagoon inhabitants. The three genera of euglenophytes which were found in the Muskegon lagoons are all common in polluted waters rich in nitrogenous organic compounds (Hutchinson, 1967).

The Ciliophora in the East Lagoon were dominated by Glaucoma and Vorticella, whereas Glaucoma, Vorticella and Cyclidium were dominant in the West Lagoon. Vorticella is often the dominant protozoan present in secondary wastewater effluent (Yarma, et. al., 1975). Since the quality of the water discharged into the East Lagoon was equivalent to wastewater undergoing secondary treatment, this genus was expected to be present. All three genera found are common components of the Ciliophora in trickling filters (Cooke, 1967).

The dominant Mastigophora present in both lagoons were the same, Bodo spp., Chilomonas nr. paramecium, Chroomonas nr. nordstedtii, and Cryptomonas nr. ovata. Bodo spp. is also a common representative of the Mastigophora in trickling filters (Cooke, 1967).

CHLOROPHYLL a

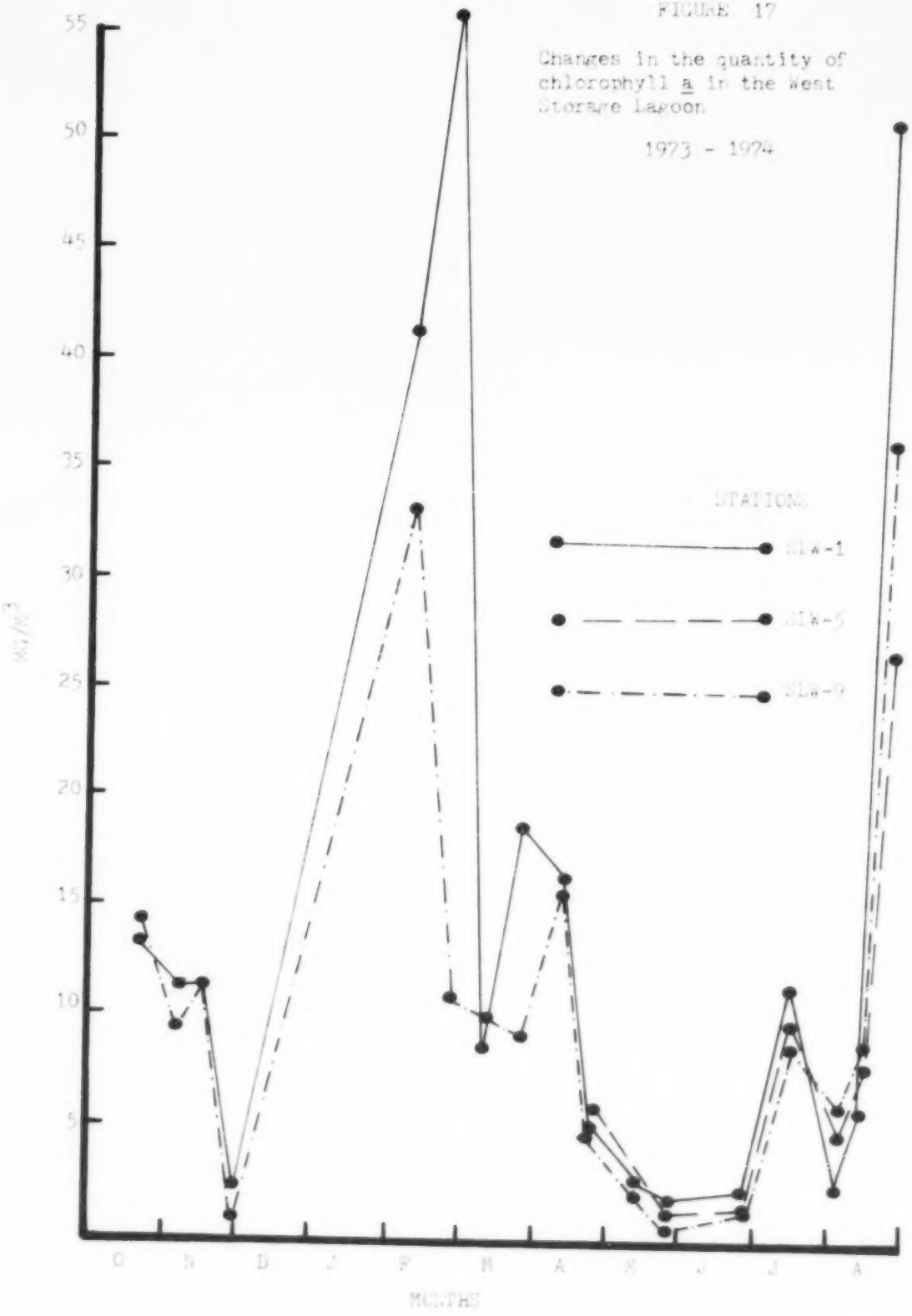
In aquatic plants, as in terrestial plants, chlorophyll is the critical component and initiates a series of physical-chemical changes which are responsible for and culminate in the fauna. Due to chlorophyll's importance in photosynthesis, chlorophyll measurements may be used as indirect indices of potential productivity (Prescott, 1962; Odum, 1971). Since the amount of chlorophyll normally increases in bodies of water as the waters become more eutrophic, chlorophyll measurements also provide comparative data on eutrophication (Mackenthun, 1973). All algae contain chlorophyll a and thus it is usually the specific pigment measured in chlorophyll determinations (Weber, 1973).

Figure 17 shows the variability in the quantity of chlorophyll a at each station throughout the year in the West Storage Lagoon. Two major peaks appeared, one during February and one in late August, 1974. The peak in February does not show a good correlation with the number of phytoplankton. On 13 February 1974, 42.99 mg chlorophyll a /m^3 was present at SLw-1 and

FIGURE 17

Changes in the quantity of chlorophyll a in the West Storare Lagoon

1973 - 1974



57.94 at SLW-9. Yet the phytoplankton counts on this date were approximately 9,400 organisms/ml at SLW-1 and only 4,400 at SLW-9. On 27 February 1974 the chlorophyll *a* concentration increased to 56.16 mg/m^3 at SLW-1 and decreased sharply to 9.7 at SLW-9, yet the phytoplankton population remained fairly constant at SLW-1 and increased sharply to 11,277.7 organisms/ml at SLW-9. Since the environmental conditions did not fluctuate greatly, and the same species, *Chlorella* nr. *vulgaris* , was dominant in all these cases, it appears that the viability of the algal cells varied during this period. If the viability of the algal cells in the Muskegon Lagoons can vary so greatly in a short period of time, the use of chlorophyll measurements as indices of productivity and/or eutrophy should be cautioned, at least in these lagoons.

Unfortunately, the East Lagoon chlorophyll samples from 26 April 1974 through 2 August 1974 were misplaced and cannot be included in these results. Due to this large block of missing data, a meaningful graph of chlorophyll *a* could not be made for the East Lagoon.

A comparison of the mean quantity of chlorophyll *a* by depth and lagoon is presented in Table 12. This table also indicates the large variability of this parameter.

The chlorophyll *a* concentrations for both lagoons are not exceedingly high compared to natural waters. Caution must be exercised, however, in making comparisons since the quantity of chlorophyll per unit of algae present is influenced by various environmental and nutritional factors, as well as the species and age or viability of the algal cells (Weber, 1973).

PRIMARY PRODUCTIVITY

The basic aim of these measurements was to provide an estimate of the quantity of organic matter which is produced from inorganic substances within the lagoons. It is assumed that during photosynthesis one molecule of oxygen is released for each atom of carbon assimilated (American Public Health Association, 1971). These measurements, therefore, also provide information concerning the rate of oxygen production, an important consideration in the heavily stressed lagoon environment.

TABLE 12

Comparison of the quantity of Chlorophyll a in the east and west lagoons. Data are given as the mean (mg/m^3) ± one standard deviation.

KEY TO ABBREVIATIONS

S = shallow sample D = deep sample B = both depths

DATE	LAGOON					
	EAST			WEST		
	S	D	B	S	D	B
10-26-73	4.2 ± 2.8			11 ± 3.9		
11- 9-73	1.7 ± 1.2			10 ± 1.8		
11-16-73	0.73 ± 0.07			12 ± 0.08		
11-30-73	0.42 ± 0.05			1.4 ± 0.84		
2-13-74	0.34 ± 0.10	0.28 ± 0.03	0.29 ± 0.09	50 ± 10		
2-27-74	0.24 ± 0.05	0.51 ± 0.34	0.38 ± 0.25	33 ± 33	35 ± 31	34 ± 26
3-13-74	0.16 ± 0.15	0.25 ± 0.00	0.20 ± 0.10	11 ± 0.43	6.7 ± 2.4	8.6 ± 2.7
3-29-74	0.12 ± 0.05	0.15 ± 0.11	0.14 ± 0.08	11 ± 8.3	17 ± 17	14 ± 11
4-12-74	0.05 ± *	0.16 ± 0.12	0.13 ± 0.09	20 ± 2.1	13 ± 1.2	17 ± 3.9
4-26-74				5.6 ± 0.95	4.7 ± 0.66	5.2 ± 0.89

TABLE 12 CONCLUDED

DATE	LAGOON					
	EAST			WEST		
	S	D	B	S	D	B
5-14-74				2.3 ± 0.06	2.8 ± 0.16	2.5 ± 0.28
5-28-74				1.1 ± 0.63	0.91 ± 0.48	1.0 ± 0.38
6-28-74				1.4 ± 0.15	2.1 ± 0.77	1.8 ± 0.62
7-10-74				10 ± 2.4	9.2 ± 0.56	9.3 ± 1.6
8- 2-74				5.3 ± 1.2	1.8 ± 0.58	3.6 ± 2.2
8- 9-74	9.1 ± 7.2	6.8 ± 2.7	8.0 ± 5.0			
8-15-74				9.3 ± 1.0	5.6 ± 3.4	7.5 ± 3.0
8-20-74	23 ± 5.2	24 ± 15	23 ± 9.3			
8-29-74				44 ± 15	33 ± 14	39 ± 14

* = only one sample

As shown in Figures 18 and 19, there was a general increase in the productivity in both lagoons during the summer. In the East Lagoon, the rates of carbon fixation ranged from a low of 0.35 mg $C/m^3/hr$ on 11 June 1974 to a very high value of 147.66 on 20 August 1974, while in the West Lagoon the rates ranged from a low of 1.11 mg $C/m^3/hr$ on 28 May 1974 in the deep sample (a depth equal to the secchi disk transparency) to a very high value of 164.93 on 29 August 1974 in the shallow sample (a depth equal to one-half the secchi disk transparency)(Table 13). These highs and lows in the West Lagoon correspond with the summer highs and lows for the concentration of chlorophyll a. Due to missing data, the same comparison cannot be made for the East Lagoon.

PHYSICAL PARAMETERS

The direction of flow of the wastewater, as controlled by the various gates, had an apparent effect upon only one parameter, secchi disk transparency, as noted below.

Secchi Disk Transparency

The transparency in the the East Lagoon was very small and consistently remained much lower than in the West Lagoon. The mean in the East Lagoon, 17.0 cm ± 3.3, was only 17.6 % of the mean in the West Lagoon, 96.3 cm ± 18.5. The lowest values were at SLE-1, the sample point closest to the discharge pipe, on all but one occasion, 9 August 1974. On this date the exit to the outlet lagoon (Fig. 1) was open and it is quite possible that the incoming wastewater was not mixing completely with the lagoon wastewater but rather was short-circuiting directly to the outlet. There was no appreciable difference during the period when the equalizing gate was open

FIGURE 18

Changes in primary productivity in the East Storage Lagoon (Ordinate is a partial 4 cycle logarithmic scale)

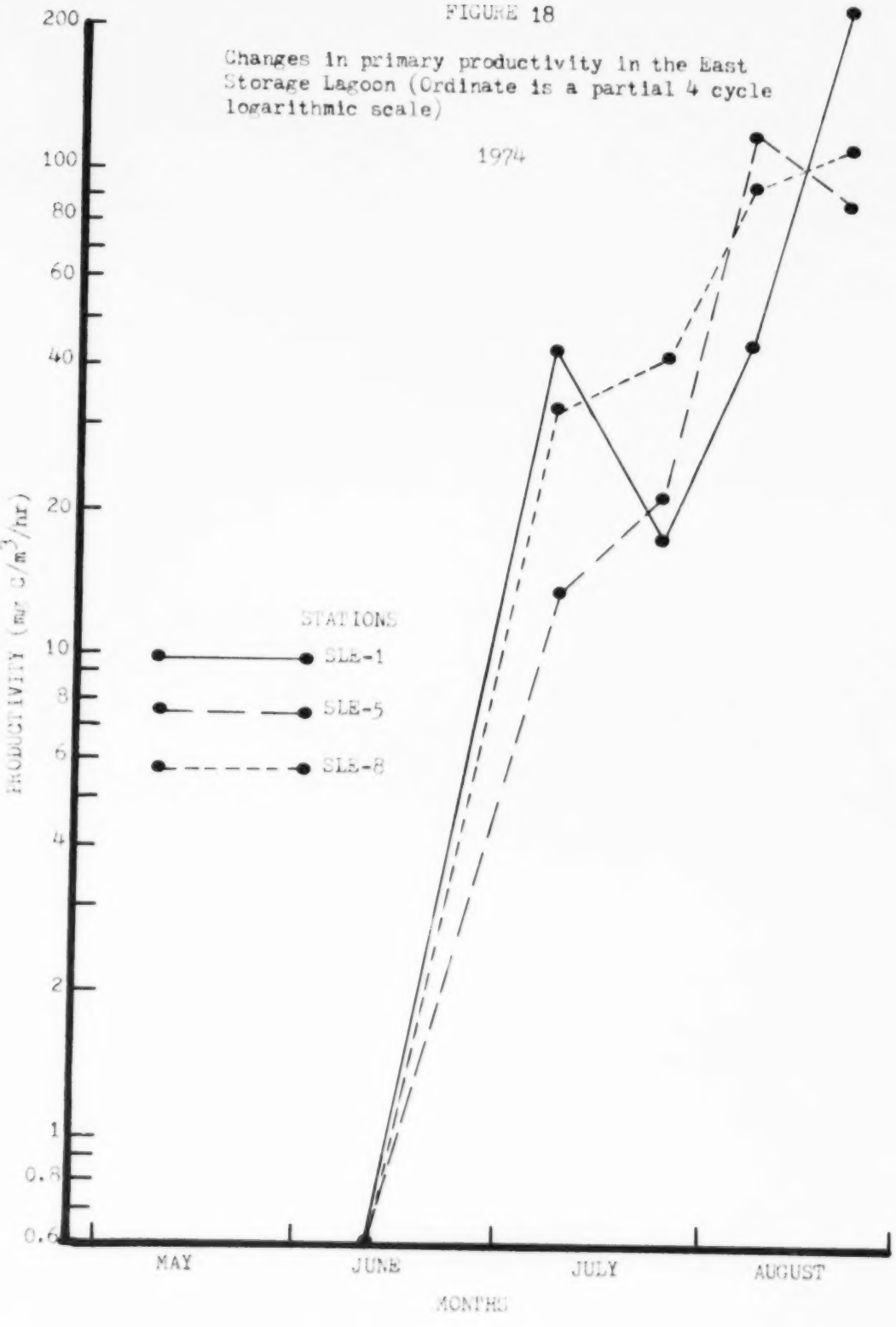


FIGURE 19

Changes in primary productivity in the west Storage Lagoon (Ordinate in a partial 4 cycle logarithmic scale)

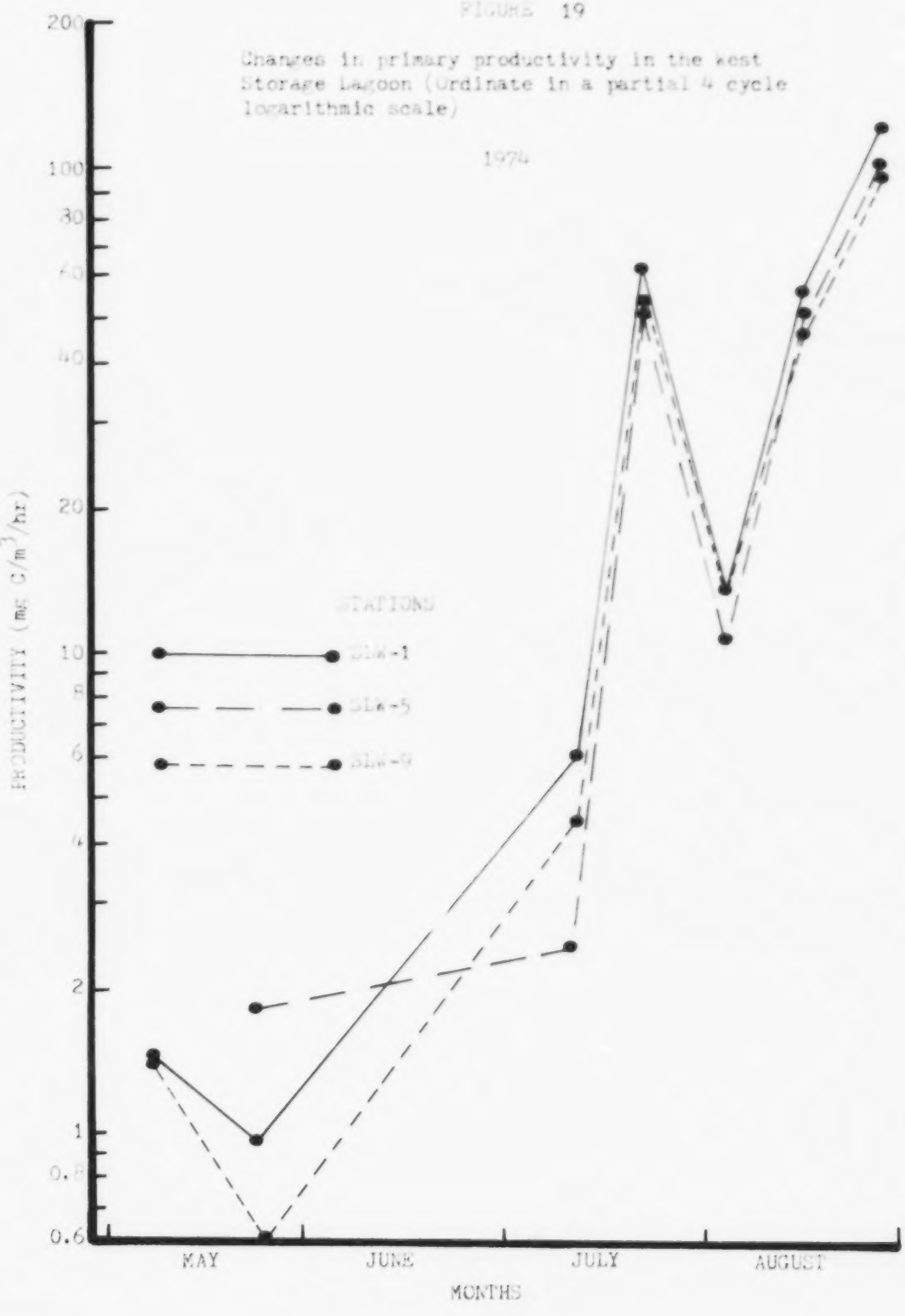


TABLE 13

Comparison of Primary Productivity in the East and West Lagoons.
Data are given as the mean (mg C/m3/hr) ± one standard deviation.

KEY TO ABBREVIATIONS

S = shallow samples D = deep samples B = both depths

DATE	LAGOON			
	EAST	WEST		
	S	S	D	B
5-14-74			1.5 ± 0.01	
5-29-74			1.1 ± 0.58	
6-11-74	0.35 ± 0.28			
7-12-74	29 ± 13		4.5 ± 1.7	
7-19-74		76 ± 13	35 ± 2.9	55 ± 24
7-26-74	27 ± 12			
8-2-74		13 ± 1.0	12 ± 2.0	14 ± 2.3
8-9-74	88 ± 43			
8-15-74		59 ± 7.3	46 ± 4.2	52 ± 8.6
8-20-74	150 ± 79			
8-29-74		160 ± 6.0	58 ± 23	110 ± 60

and water flowed from the East Lagoon into the West Lagoon.

Turbidity

With the exception of SLE-1, turbidity was fairly constant at each station and depth, and the only apparent major trend was higher turbidity in the wastewater East Lagoon than in the seepage-water West Lagoon (Table 14). In the West Lagoon, the range was from a low of 1.7 FTU to a high of 7.4, with only minor differences between the two depths at each station. In the East Lagoon the turbidity at station SLE-5 was always close to the turbidity at SLE-6. At SLE-1, though, the turbidity was consistently much higher and showed more variability between the two depths. This station is the closest to the inflow of the semi-treated wastewater. The range at SLE-1 was from a low of 4.2 FTU to a high of 34, while at the other two stations in the East Lagoon the range was from a low of 3.7 to a high of 16.

Since turbidity did not correspond with the fluctuating plankton population, and since the turbidity at SLE-1 was much greater than at any other station, it appears that suspended matter such as clay, silt, and finely divided organic and inorganic detritus rather than aquatic organisms accounts for the majority of the turbidity.

Conductivity

With the exception of one sample, the conductivity at each station in the East Lagoon consistently remained higher than at each station in the West Lagoon (Table 14). There were minor variations between stations and depths within each lagoon, and an overall increase in conductivity throughout this investigation.

TABLE 14

Comparison of Turbidity, Secchi Disk Transparency, pH, and Conductivity in the East and West Lagoons. Data are given as the mean ± one standard deviation.

PARAMETER	LAGOON	
	EAST	WEST
Turbidity, FTU	11.7 ± 6.9	3.5 ± 1.5
Secchi Disk Transparency, cm	17 ± 3	96 ± 18
pH	7.7 ± 0.2	8.1 ± 0.3
Conductivity, micro-mhos	970 ± 221	711 ± 196

Temperature

The mean temperature ± one standard deviation for each lagoon and sampling date is presented in Table 15. There was very little variation in water temperature between stations and between the two depths sampled on the same date, except for slight elevation in temperatures at SLE-1 in the winter months due to the incoming wastewater. There was, of course, a great deal of seasonal variation.

pH

The West Lagoon was slightly more alkaline than the East Lagoon (Table 14). Periods of high photosynthetic activity did not appear to elevate the pH in either lagoon, indicating a good buffering capacity in these waters.

DISSOLVED OXYGEN AND BIOCHEMICAL OXYGEN DEMAND

The mean DO and BOD ± one standard deviation for each sampling date and each lagoon is presented in Table 15. The direction of flow of the wastewater, as controlled by the various gates, had little apparent effect upon these parameters.

Dissolved Oxygen

With the exception of 9 November 1973, and immediately after the ice

TABLE 15

Comparison of Temperature, Dissolved Oxygen, and Biochemical Oxygen Demand in the East and West Lagoons. Data are given as the mean ± one standard deviation.

KEY TO ABBREVIATIONS:

TEMP = Temperature, ^{o}C DO = Dissolved Oxygen, mg/l BOD = Five day Biochemical Oxygen Demand, mg/l

DATE	LAGOON					
	EAST			WEST		
	TEMP	DO	BOD	TEMP	DO	BOD
10-26-73	10.3 ± 0.3	3.1 ± 1.9	14.7 ± 13.3	10.0 ± 0.0	8.4 ± 0.2	3.7 ± 2.5
11- 9-73	9.3 ± 0.4	8.1 ± 4.5	19.2 ± 16.8	9.3 ± 0.4	11.8 ± 0.1	4.4 ± 0.2
11-16-73	9.0 ± 0.0	5.2 ± 3.5	19.5 ± 22.0	9.0 ± 0.0	10.5 ± 0.4	1.6 ± 0.5
11-30-73	7.8 ± 0.4	7.0 ± 4.0	32.5 ± 30.4	7.5 ± 0.0	11.6 ± 0.4	0.5 ± 0.7
12-21-73	0.8 ± 0.3	3.7 ± 2.4	34.5 ± 27.6	0.5 ± 0.0	14.2 ± 1.1	6.5 ± 0.7
1- 2-74	0.5 ± *	3.9 ± *	**	0.0 ± 0.0	13.6 ± 0.3	**
1-16-74	2.0 ± 0.0	0.2 ± 0.1	16.0 ± 4.2			
1-30-74	2.4 ± 0.8	1.4 ± 2.3	15.3 ± 5.5	1.0 ± 0.0	10.8 ± 1.3	7.0 ± 0.0
2-13-74	2.2 ± 0.3	0.3 ± 0.2	14.0 ± 2.3	0.8 ± 0.3	12.9 ± 2.5	5.6 ± 3.2
2-27-74	1.5 ± 0.6	0.0 ± 0.0	19.8 ± 3.3	0.8 ± 0.3	11.2 ± 1.8	6.8 ± 4.1

TABLE 15 CONTINUED

DATE	[illegible]					
	[illegible]			[illegible]		
	TEMP	DO	BOD	TEMP	DO	BOD
3-13-74	3.8 ± 0.3	2.6 ± 0.8	12.2 ± 2.6	5.1 ± 0.2	12.2 ± 0.1	4.5 ± 0.6
3-29-74	3.0 ± 0.6	7.6 ± 1.6	14.2 ± 0.5	1.5 ± 0.6	14.4 ± 1.2	5.2 ± 0.9
4-12-74	8.8 ± 0.4	3.0 ± 0.8	15.3 ± 7.6	6.0 ± 0.0	10.2 ± 0.3	4.0 ± 3.1
4-26-74	12.3 ± 0.5	2.9 ± 0.6	11.5 ± 6.2	12.6 ± 0.9	5.4 ± 0.4	4.7 ± 0.5
5- 7-74	14.1 ± 0.9	2.6 ± 1.1	19.8 ± 9.7			
5-14-74				11.0 ± 0.0	8.6 ± 0.4	4.2 ± 1.2
5-21-74	17.5 ± 0.6	1.4 ± 0.7	5.1 ± 2.7			
5-28-74				16.0 ± 0.0	7.2 ± 0.3	2.6 ± 0.4
6-11-74	20.0 ± 0.0	2.1 ± 0.9	31.9 ± 3.0			
6-25-74				22.3 ± 0.7	5.4 ± 0.2	7.2 ± 1.2
7-12-74	27.0 ± 0.6	0.1 ± 0.1	17.8 ± 5.7			
7-19-74				25.6 ± 0.2	6.4 ± 0.3	3.6 ± 1.0
7-26-74	24.2 ± 0.3	0.5 ± 0.0	17.0 ± 3.5			

TABLE 15 CONCLUDED

DATE	LAGOON					
	EAST			WEST		
	TEMP	DO	BOD	TEMP	DO	BOD
8- 2-74				23.4 ± 0.2	6.8 ± 0.2	3.5 ± 0.0
8- 9-74	24.9 ± 0.2	1.6 ± 1.1	16.0 ± 2.7			
8-15-74				23.0 ± 0.0	8.5 ± 0.2	2.6 ± 1.9
8-20-74	25.0 ± 0.0	2.4 ± 1.9	***			
8-29-74				23.0 ± 0.0	11.9 ± 1.0	****

* = only one sample
** = bad dilution water
*** = all DO consumed
**** = incubator broken

broke up on 29 March 1974, the mean DO levels consistently remained very low in the East Lagoon, and much below the DO levels in the seepage-water West Lagoon. During the first several months of this investigation, there was a large difference in the DO levels between stations in the East Lagoon, as evidenced by the large standard deviations (Table 15). The DO at SLE-1 was quite a bit lower than at SLE-8. By 2 January 1974, however, the DO had dropped at SLE-8 and it remained more uniform within the lagoon on all subsequent sampling dates. There were two periods of especially low DO in the East Lagoon, one during ice-cover and the other during July and August, when the water temperatures were at their maximum (Fig. 20). The DO levels in the West Lagoon did not experience a similar decline during the ice-cover, but did experience an early summer decline, with recovery in August during the phytoplankton bloom (Fig. 21). This was the only algae bloom which coincided with a peak in DO. None of the other phytoplankton peaks are evident by observing the DO values, suggesting that there may be significant heterotrophic algae growths occurring in both lagoons, a common situation in other wastewater lagoons (Bajic and Chiu, 1970; Wiedeman, 1970).

Biochemical Oxygen Demand

The BOD was consistently higher in the East Lagoon than in the West Lagoon, due to the high amount of organic matter in the wastewater. This, in part, accounts for the lower DO levels in the East Lagoon.

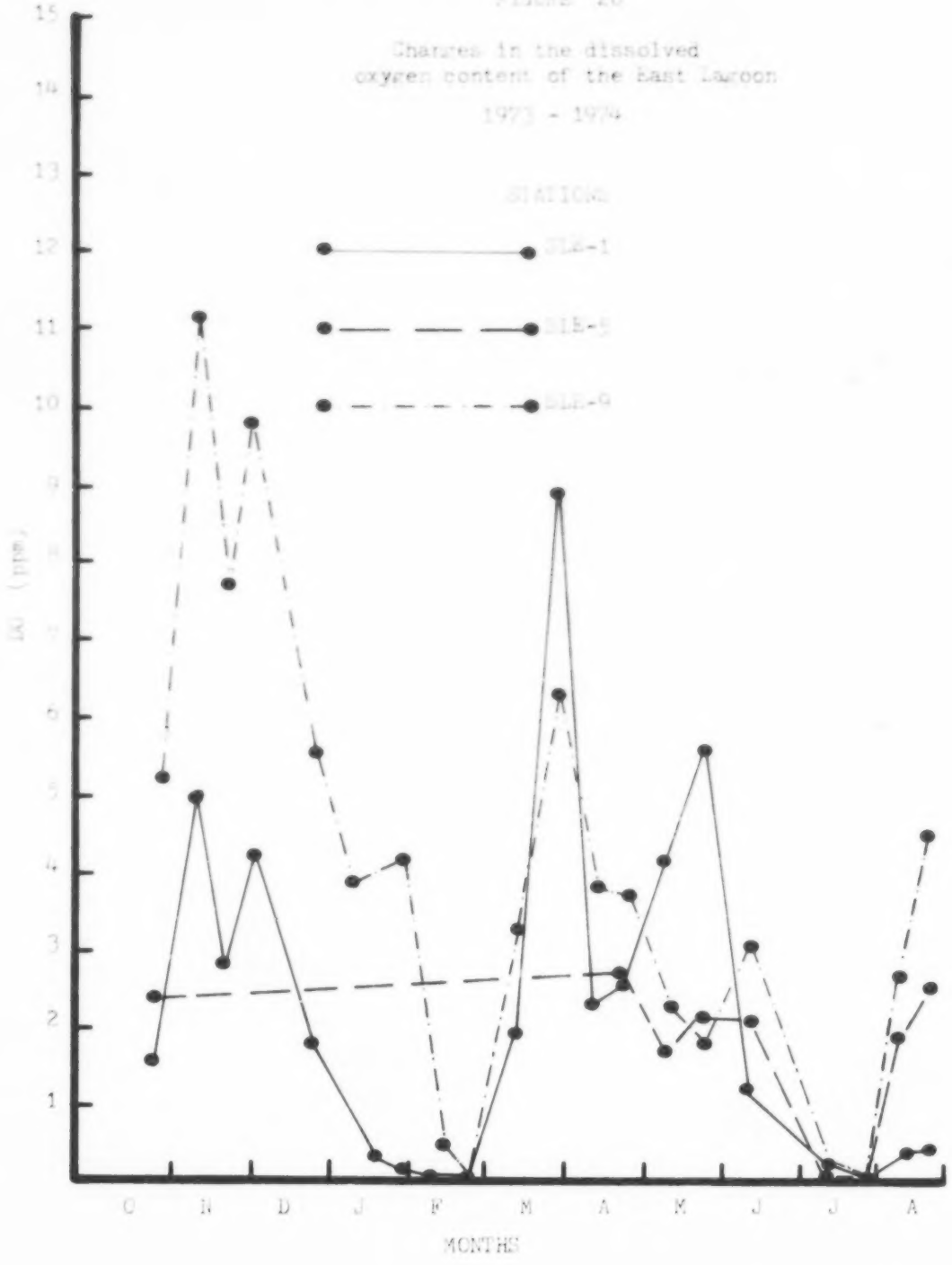
Similar to the situation for DO, during the first several months of this investigation there was a large difference in the BOD levels between stations in the East Lagoon, as evidenced by the large standard deviations (Table 15). By January, however, the wastewater constituents had obtained a more homogeneous distribution within this lagoon and the BOD at SLE-1 was close to the BOD at SLE-8 (Fig. 22).

TOTAL ORGANIC CARBON

The overall mean concentration of total organic carbon (TOC) in the East Lagoon, 41.6 mg/l ± 12.9, was much greater than the mean in the West Lagoon, 26.2 ± 17.6. On only two occasions did the West Lagoon have a

FIGURE 20

Changes in the dissolved oxygen content of the East Lagoon 1973 - 1974



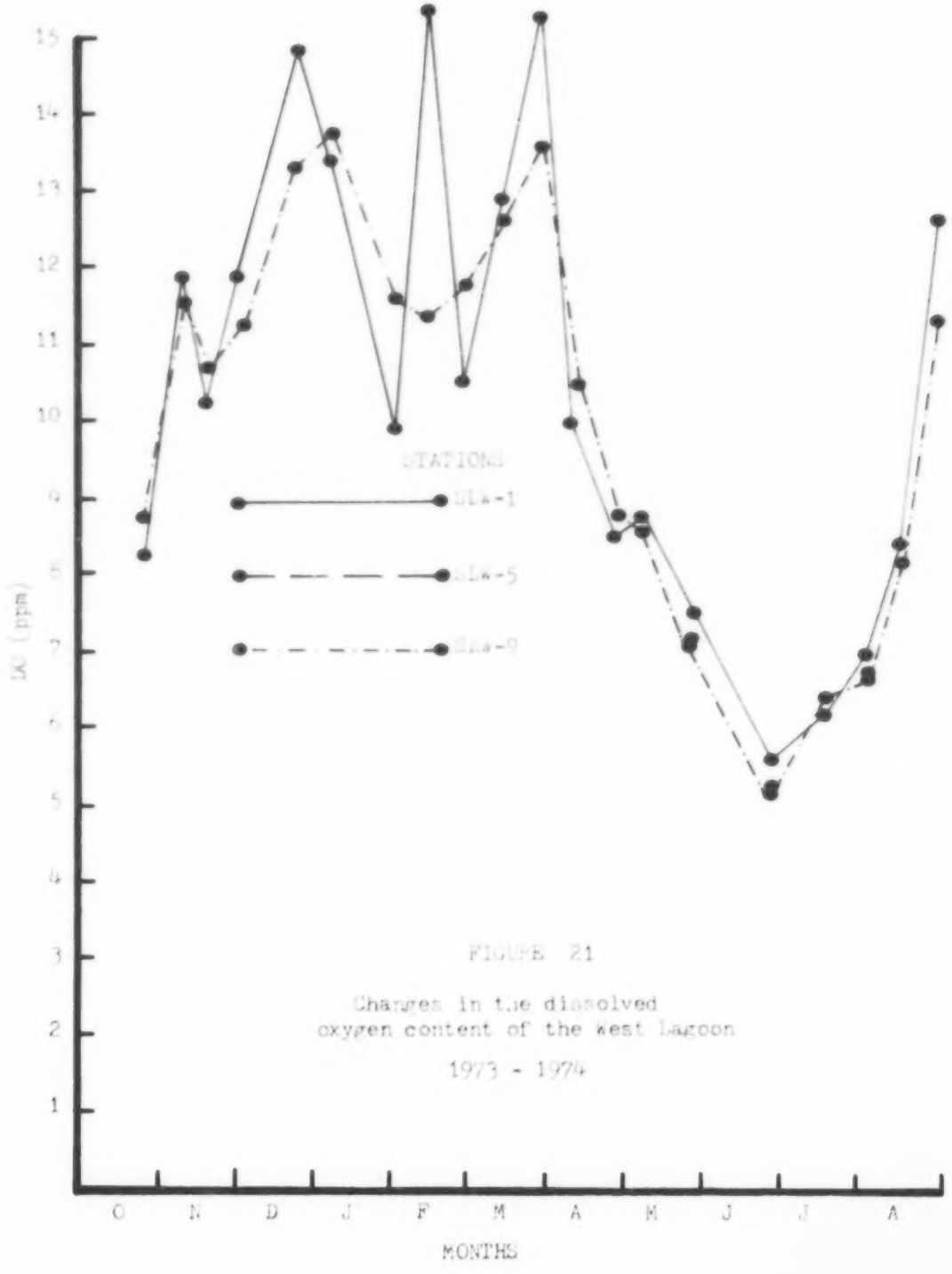


FIGURE 21

Changes in the dissolved oxygen content of the West Lagoon

1973 - 1974

FIGURA 22

Changes in the biochemical oxygen demand in the East Lagoon

1973 - 1974

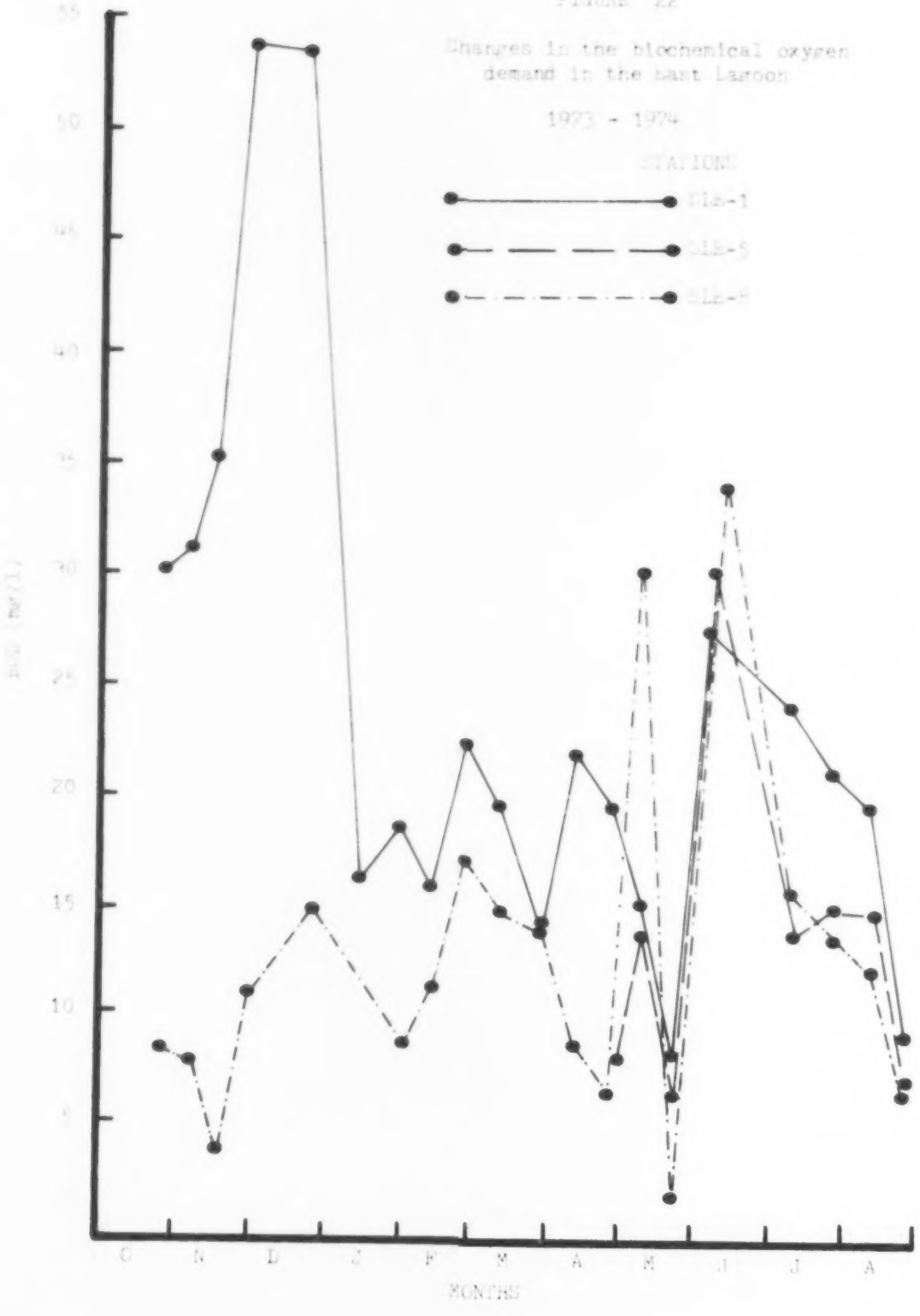
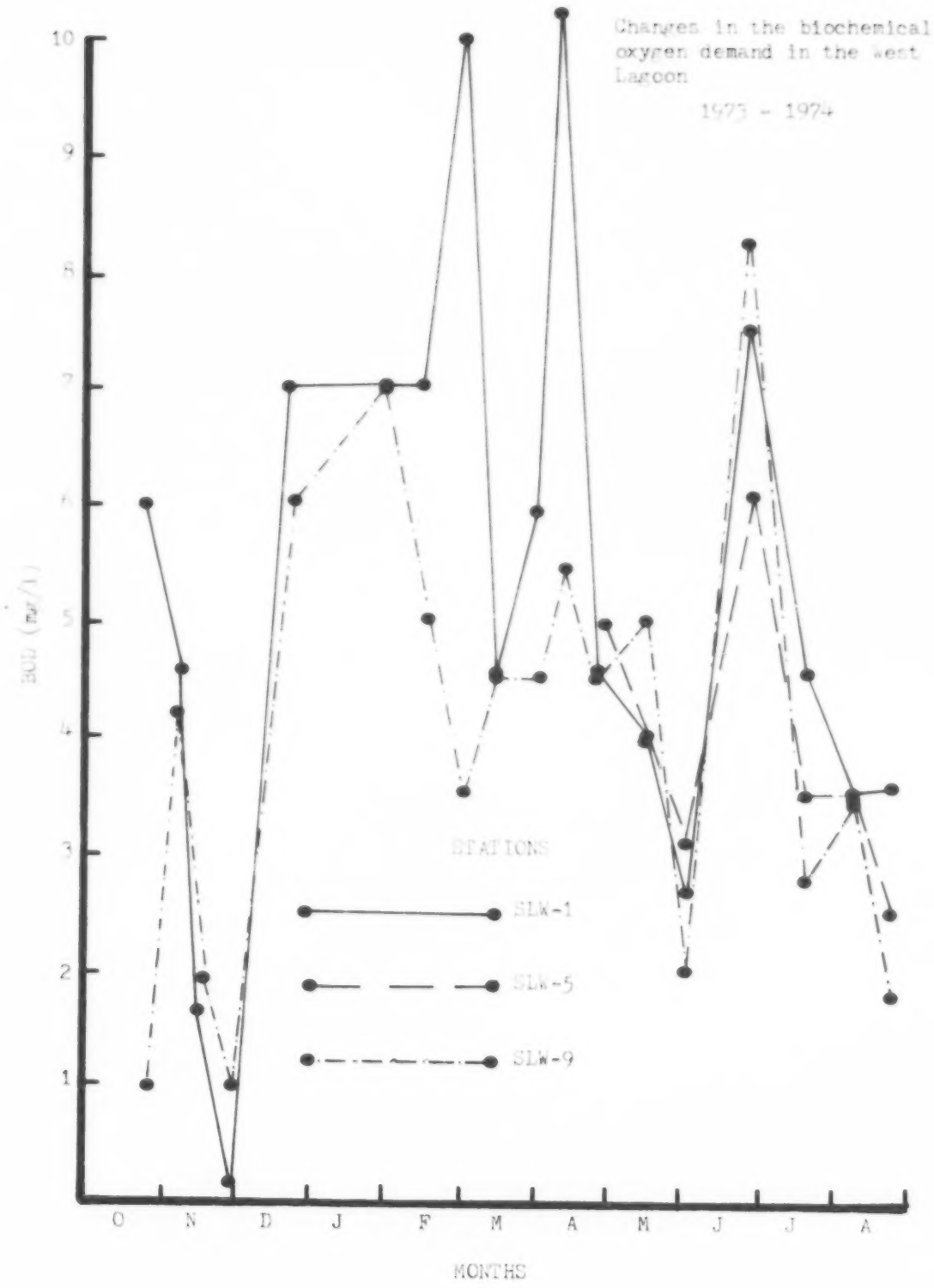


FIGURE 23


Changes in the biochemical oxygen demand in the West Lagoon
1973 - 1974
BOD (mg/l)
10
9
8
7
6
5
4
3
2
1
STATIONS
SLW-1
SLW-5
SLW-9
O
N
D
J
F
M
A
M
J
J
A
MONTHS

greater amount of total organic carbon. These pulses, on 29 March 1974 and 14 May 1974, do not correspond to any phytoplankton bloom and are unexplainable with the present data. Total organic carbon was more homogeneous in the West Lagoon than in the East Lagoon.

NUTRIENTS, ANIONS AND METALS

Table 16 summarizes these data and presents, for each parameter, the mean ± one standard deviation. Ammonia nitrogen was the only parameter noticeably affected by a change in the flow due to gate positions.

Ammonia Nitrogen

Due to the high levels of ammonia in domestic and industrial wastes, the concentration of ammonia nitrogen was much higher in the East Lagoon than in the West Lagoon . The ammonia nitrogen concentration in the West Lagoon was very often below 0.1 mg/l, and the mean concentration for the entire year was only 4.3% of the mean in the East Lagoon.

In the East Lagoon from 2 January 1974 through 11 June 1974 there was an overall general rise in the amount of ammonia, from a low of 1.0 mg/l to a high of 5.4. Throughout the remainder of this study, however, the ammonia levels decreased in this lagoon to a low of 0.7 mg/l on 20 August 1974. Just prior to this period of rapid decline in ammonia levels, the wastewater flow pattern was altered in the East Lagoon. The gate to the outlet cell was opened, thus allowing the incoming wastewater to enter the East Lagoon, but instead of mixing with the lagoon water, it could immediately flow out to be used for irrigation water. It appeared, from the flow of surface foam and color, that this short-circuiting was occurring. However, secchi disk transparency was the only other parameter to bear this out. This could possibly be due to the fact that ammonia is rapidly oxidized to nitrite and nitrate nitrogen, and therefore, in order to maintain the high levels of ammonia which were present, a continual influx was required. Without continual replenishment, the ammonia levels plummetted. This fluctuation accounts for a great deal of the rather large standard deviation. Most of the other parameters do not change form so rapidly, and thus the levels could not drop as quickly.

Nitrate Nitrogen

The difference between the concentration of nitrate nitrogen in the two lagoons was much less than for ammonia. There was a great deal of fluctuation in the nitrate levels, as evidenced by the large standard deviations.

Orthophosphate

Due to the high amount of phosphate in domestic sewage, the mean concentration of orthophosphate in the East Lagoon was quite high, 4.47 mg/l ± 1.23, and 5.5 times greater than the mean of 0.80 ± 0.97 in the West Lagoon. Unlike the situation in many natural waters, phosphorous does not seem to limit phytoplankton growth or control standing crops in the wastewater East Lagoon.

The great fluctuations in the concentrations of orthophosphate in the West Lagoon is puzzling. In January 1974 the concentration was 2.3 and 3.8 mg/l, and yet on the next four consecutive samples, during February and March 1974, it was less than 0.1 mg/l. This fluctuation accounts for the very large standard deviation.

Sulfate

Sulfate levels were not high and were quite homogeneous within each lagoon. The mean concentration in the West Lagoon, 71.5 mg/l ± 14.6, was 76.7% of the mean in the East Lagoon, 93.2 mg/l ± 13.9.

Chloride

The concentration of chloride in each lagoon was high and very evenly distributed among the three stations in each lagoon. There was only minor variation in the chloride levels during this investigation, with the concentration of this ion being consistently higher in the East Lagoon. This is as expected, since chloride is usually higher in sewage than in raw water because sodium chloride passes uncharged through the digestive system.

Metals

With the exception of magnesium, a common constituent of natural waters, the concentration of each of these parameters was higher in the East Lagoon than in the West Lagoon. Sodium levels were much higher in the wastewater East Lagoon than in the West for the same reason that chloride was much higher.

TABLE 16

Comparison of Nutrient, Anion, and Metal Data in the East and West Lagoon. Data are given as the yearly mean (mg/l) ± one standard deviation.

PARAMETER	LAGOON	
	EAST	WEST
Ammonia Nitrogen, NH_4-N	2.89 ± 1.81	0.12 ± 0.16
Nitrate Nitrogen, NO_3-N	1.00 ± 1.03	0.64 ± 0.33
Orthophosphate, PO_4	4.47 ± 1.23	0.80 ± 0.97
Sulfate, SO_4	93.2 ± 13.9	71.5 ± 14.6
Chloride, Cl	159.2 ± 12.9	100.0 ± 16.2
Calcium	63.3 ± 8.4	53.4 ± 7.2
Magnesium	15.80 ± 1.51	17.25 ± 1.31
Sodium	145.3 ± 9.7	90.1 ± 13.4
Potassium	12.05 ± 1.21	5.44 ± 0.84
Manganese	0.234 ± 0.036	0.043 ± 0.021
Zinc	0.206 ± 0.041	0.081 ± 0.039
Iron	0.920 ± 0.166	0.788 ± 0.394

SECTION V

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